# UNIVERSITY OF EDUCATION, WINNEBA

# USING MICRO CHEMISTRY EQUIPMENT ACTIVITIES TO IMPROVE UNDERGRADUATE TEACHER – TRAINEES' CONCEPTIONS OF SELECTED INORGANIC CHEMISTRY TOPICS

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# USING MICRO CHEMISTRY EQUIPMENT ACTIVITIES TO IMPROVE UNDERGRADUATE TEACHER-TRAINEES' CONCEPTIONS OF SELECTED INORGANIC CHEMISTRY TOPICS

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**(MPhil Analytical & Environmental Chemistry)**

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**DECEMBER, 2014**

# DECLARATION

## STUDENT'S DECLARATION

I, RUBY HANSON, hereby declare that this thesis, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and has not been submitted, either in part or whole for another degree elsewhere.

SIGNATURE: ………………….

DATE: ………………………….

## SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of thesis as laid down by the University of Education, Winneba.

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I thank them all.

# DEDICATION

This piece of work is dedicated to my children.

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## ABSTRACT

The study was aimed at improving on 48 teacher-trainees‟ concepts in an introductory inorganic chemistry course through practical micro chemistry equipment (MCE) activities and curriculum materials. These materials were validated through scrutiny by experts in Chemistry Education, trials in a comparable institution and Kuder-Richardson‟s formula, KR-20. Some of the topics which were covered in the study were the nature of solutions, chemical stoichiometry, balancing of equations, periodicity and hybridisation. A practical approach to instruction was adopted while using MCE as an interventive tool. The study was an action research. Data were collected from an intact class of 48 regular first year chemistry teacher-trainees at the University of Education, Winneba, by means of a two-tiered diagnostic concept test, classroom lessons and MCE-activities during chemistry periods. Semi-structured interviews, questionnaires and observation schedules were employed to triangulate the data. There was also an evaluation of students‟ acquired skills in the use of the micro-chemistry equipment as they were trained in the use of MCE, which they could access readily and handle without fear of damage. The activities were also to imbue them with the skills of using the MCEs to design more authentic chemistry practical activities when they move to the schools as classroom teachers. Students were expected to gain concept, process and laboratory skills. From the study, it was found that the MCE approach enhanced practical skills acquisition and chemistry concept formation. The implications of the results for the teaching and learning of chemistry concepts are that teaching through the MCE-concept approach has the potential to change the way chemistry is taught and learned in a more interactive, exciting, simple and easy way. In addition, MCE activities developed in this study would be feasible for use in other institutions of learning.

# CHAPTER ONE

# INTRODUCTION

## Overview

This chapter contains a prologue to the study, the background to the study, statement of the problem, rationale for the study and objectives of the study. Also presented are the significance of this study, its limitations, delimitations, and a summary of the chapter.

## Background to the Study

Chemistry is mainly an experimental, observational and laboratory-oriented discipline, so chemistry lessons must be structured to reflect their practical nature. From the Researcher"s own observation, a lot of schools teach science without relevant and adequate practical activities. Government has made efforts to supply equipment for the study of science in all sectors of education; yet activities are hardly performed. Most of these equipment supplies are imported and made of large-sized glassware that range from $5cm^3$ to about $1000\ cm^3$ capacities or more. These supplied equipment require the use of large quantities and volumes of chemicals. A tour around some senior high schools and colleges of education in three regions of Ghana by the Researcher, to assess equipment supply by government, revealed inadequate equipment in the institutions. Equity in supply of equipment to the government schools in Ghana appeared not to have been achieved, as urban schools had more and regular supply than schools in the hinterlands (Adegoke, 2003). The adoption of semi-micro, ultra-micro and sub-microgram activities which makes less demand on chemicals and other resources would be useful for schools (Abdullah, Mohamed, & Hj Ismail, 2009). The Researcher is of the opinion that the usage of tiny, more robust miniature plastic equipment would serve the needs of both urban and rural schools, and stand the test of time, as breakages would be minimised. Also, because of the cheap cost of the miniature equipment, the problem of equity of supply to schools would be overcome.

With the supply of science equipment to schools, it is hoped that learners would be engaged in more activities so that they would be able to construct authentic science concepts. However, Demircioglu, Ayas and Demircioglu (2005), Canpolat, Pinarbasi, Bayrakceken and Gehan (2006), Coll and Taylor (2010) and Bell and Bradley (2012), intimate that unless learners actually engage in science practical activities, alternative conceptions which they come to class with, will not be changed (Taber & Tan, 2007). This implies that teachers themselves will have to know and confront their own alternative conceptions and know about learners‟ common misconceptions as well as conceptual change approaches (Edwards & Hammer, 2004; Gooding & Metz, 2011). Hanson (2014a; 2015) identified in studies done in a teacher training institution in Ghana that teacher trainees had various alternative conceptions about some organic and inorganic chemistry topics. Thus, it is imperative that teacher trainees become aware of the complexities of embarking on conceptual change approaches for best possible results in their teaching careers and the best possible approaches to use for sound concept formation among learners.

**Problem Statement**

The University of Education, Winneba Chemistry Department syllabus, (Department of Chemistry Education, 2013) requires that chemistry teacher trainees be equipped with practical and experimental skills. The syllabus stresses the importance of teaching chemistry, based on practical activities for concept development. It also requires that the activities be developed to lead to authentic science concept and skills development. In teaching practical skills, teacher-trainees should be actively involved in the search for practical solutions to problems and tasks. The teacher is expected to provide opportunities for trainees to acquire a high level of proficiency in the use of tools and equipment for scientific work. The laboratory experiences are supposed to give trainees a wide range of learning experiences to develop inquiry minds, but UEW chemistry teacher-trainees‟ laboratory activities suggest that they only verify textbook claims, as was discovered by Tsai (2003) in a similar situation in Taiwan. Huber (2001) also found in a study that „canned recipe‟ style activities limit the way in which students interact with materials and learn through their use. He added that they follow steps for activities methodically to arrive at successful conclusions without understanding the science concepts behind them. Other skills to be developed by the trainees are persistence in the execution of experimental activities and modification of experimental activities where necessary, in order to reach deductive or formative conclusions.

The senior high school chemistry syllabus (Ministry of Education, Science and Sports, 2008), like the UEW chemistry syllabus stresses the need for students to be trained in laboratory, concept and process skills for the development of conceptual understanding necessary for developing scientific concepts. The Researcher‟s observations from some schools indicate that teachers do not design appropriate skills and concept-based activities for students to benefit from the practice of science. The designed activities are more like „cook book‟ recipes where students follow several hints to arrive at conclusions. Many reasons, such as overload of the chemistry syllabus, lack of equipment and chemical resources, were adduced as the reasons for teachers‟ failure in organising more authentic practical chemistry activities.

Besides external problems of work overload, lack of equipment and chemical resources and the development of skills are conceptual issues. Both teachers and students have their own misconceptions (herein called alternative concepts) which they develop through many means as they interact with the world in which they live. Parents, traditional stories, teachers, multimedia, and learners themselves are responsible for cultivating and fostering misconceptions. Despite teachers‟ best efforts, students continue to design their own versions of reality. Science curricula and textbooks are also responsible for perpetuating misconceptions. Sometimes, concepts are introduced without regard to student readiness. Topics are introduced when students are not developmentally or psychologically ready to learn them. These problem learning situations all culminate in various types of misconceptions. These different misconceptions have been classified by Gooding and Metz (2011) as:

1. Preconceived notions,
2. Non-scientific beliefs,
3. Conceptual misunderstandings,
4. Vernacular misconceptions, and
5. Factual misconceptions.

Thus, MCE- based lessons which would equip teacher trainees with the requisite skills to help them undertake activities which lead to authentic concept development, was the focus of this study.

**Rationale**

The study was conducted upon the premise that the use of micro-chemistry equipment has the potential to imbue chemistry teacher-trainees with laboratory manipulative skills, process skills, as well as to enable them to build chemistry concepts. Baseline studies done in the 2011/12 academic year at UEW and at a similar teaching institution by the Researcher showed that most chemistry teacher-trainees exhibited inaccurate manipulative skills and hardly articulated correct chemistry concepts in their explanations. There appeared to be a mismatch between intentions and reality during practical activities which led to the formation of alternative concepts by teacher-trainees. Thus, laboratory activity objectives were not attained at the end of the laboratory activities. Few trainees interviewed intimated that they needed more hands-on activities to enhance their practical skills acquisition. This might have possibly been due to unavailability of large quantities of chemicals for the trainees to have many laboratory sessions. It was hoped that with the introduction of micro chemistry equipment, which enables small quantities of chemicals to be used, the trainees would be able to have many laboratory sessions. It was also expected that the trainees" engagement in numerous laboratory sessions would improve their practical skills acquisition and enhance their chemistry concept development.

**Purpose of the Study**

The study was used, in the first place, to unearth trainees" conceptualisation of some basic chemistry principles through a baseline data collection. This was done through a pre-intervention test administered on practical activities chosen from the trainees" first semester practical chemistry course. Also in this study, ten lessons were organised on chemistry topics meant for the second semester. Some of the topics covered in these lessons were the particulate nature of matter (PNM), chemical bonding, periodicity, hybridisation, solubility, equations, mole and stoichiometry (EMS), pH and the nature of acids and bases. Then, a post-intervention test was administered on practical activities that were in consonance with the topics covered during the lessons. Finally, the trainees were interviewed to find out their impressions about the use of the micro equipment which they engaged with throughout the lessons. The findings from the study enabled the Researcher to develop a teaching manual based on the use of micro equipment for laboratory work in the senior high schools.

**Objectives of the Study**

The study was set up to:

1. administer a two-tiered diagnostic test to unearth trainees‟ chemistry concepts on some inorganic chemistry topics
2. determine learning skills that trainees who are trained to use the micro chemistry equipment to develop their practical activities would demonstrate
3. determine the types of chemistry concepts that would emerge out of the trainees‟ understanding of the practical activities that they perform
4. identify characteristics of the MCE that would be suitable for the development of MCE-based activities in the form of a teaching manual
5. find out if teaching through the MCE approach would significantly change the way of the selected inorganic chemistry topics are learned

**Research Questions**

The following research questions were addressed in the study:

1. What types of concepts in inorganic chemistry would trainees come out with on the two-tiered test?
2. What skills would trainees, who are trained to use micro chemistry equipment for practical activities, demonstrate in developing their practical activities?
3. What types of chemistry concepts would emerge out of the trainees‟ understanding of the practical activities they perform?

4. What characteristics of the micro equipment activities would be suitable for developing a teaching manual?
5. Would teaching through the MCE approach significantly change the way the selected inorganic chemistry topics are learned?

**Significance**

This study was expected to unearth some scientific concepts and alternate concepts of teacher-trainees. These concepts and alternate concepts would be documented and it is expected that teachers and students who read them would be informed about why such concepts may be prevalent among students. Furthermore, the study would document how to correct alternate concepts through the use of simple laboratory experiments. It is hoped that teachers, and whoever reads this work, would be informed on how they can correct alternate concepts through the use of simple experiments. Finally, the study would come out with a teaching manual that would be useful to senior high school teachers as well as students who may lay hands on the document for teaching or learning.

**Limitations**

The study should have covered the entire chemistry education students in the Chemistry Department. However, time constraints, availability of participating students, as well as the depth of the study limited, the Researcher‟s activities to an interaction with an intact class of 48 chemistry teacher trainees.

**Delimitations**

The study was an action research and so could not generalise the effect of the micro chemistry equipment (MCE) on basic inorganic chemistry to all areas of chemistry. Besides, some of them would not be compatible with MCE activities. More sophisticated monitoring equipment, lengthier study periods, and a wider scope of chemistry would be required for those areas of study. Teacher trainees in other second and third year chemistry classes were studying organic, physical and environmental chemistry which did not fall under the basic inorganic chemistry topics which were studied. Thus, the said groups could not be included in the current study.

**Summary of Chapter One**

Discussed in this chapter are some of the perceived problems of organising practical chemistry activities in Ghanaian schools. The deliberations so far provide evidence for the effectiveness of the use of MCE to help students to gain faster and more permanent understanding of the science concepts they are taught. This chapter has also shown that the knowledge gained from the present study would equip teacher-trainees with adequate skills to be able to create similar or new products for doing conceptual teaching, by using low-cost resources through novel designs and constructions. These focal points have been the motivation for this study. The introduction has also reiterated the fact that other equally miniature cheap resources could be improvised for use once a teacher has gained an understanding of calibrating other useful and useable low-cost equipment. The study has used the outcomes of trial lessons to develop a chemistry manual that may be used for the teaching of chemistry in Ghanaian senior high schools.

The thesis has been structured in such a way that Chapter 2 reviews the relevant literature for the use of Micro Chemistry Equipment in schools and the general usefulness of such micro-equipment in deprived schools. It discusses some of the issues which could lead to the formation of alternative concepts, some best methods of teaching for improving concept understanding and why there would be a need for a developmental research. Presented are reviews on the relationship between practical chemistry activities and concept development as well as the principles of learning which underlie the various theories of learning. This is followed by Chapter 3 in which the methodology of the study has been outlined. In Chapter 4, data collected on trainees‟ views about MCE (using various data collection techniques), as well as implementation of some instructional strategies with micro-equipment, have been presented. In Chapter 5, the results of the implementation and evaluation of an intervention to improve teaching and students‟ conceptual understanding of topics in chemistry have been discussed. Finally in Chapter 6, conclusions drawn from the findings of the study, and recommendations for various stakeholders in education, have been outlined.

## Acronyms and Abbreviations

COE: College of Education

CRDD: Curriculum Research and Development Division

EMS: Equations, mole and stoichiometry

GES: Ghana Education Service

IUPAC: International Union of Pure and Applied Chemistry

MC: Micro chemistry

MCE: Micro Chemistry Equipment

MCT: Multiple Choice Test

MOESS: Ministry of Education, Science and Sports

PNM: Particulate Nature of Matter

PRACTICAL: Programme Reform and Alignment for Increasing Competencies of Teachers and for Improving Comprehension and Application in Learning Science and Mathematics

PRET: Pre-two-tiered test

PREM: Pre-two-tiered multiple choice test

RADMASTE: Centre for Research and Development in Mathematics, Science and Technology Education

SHS: Senior High School

SPSS: Statistical Package for Social Science

TTT: Two-tiered test (A two-part test item)

UEW: University of Education, Winneba

UNDP: United Nations Development Programme

UNESCO: United Nations Educational Scientific and Cultural Organisation

USAID: United States Agency for International Development

WAEC: West African Examinations Council

# CHAPTER TWO

# LITERATURE REVIEW

## Overview

In this chapter, the Researcher has discussed the context of the study vis a vis the importance of laboratory work and its effect on the development of chemistry concepts. The use of science equipment in Ghana, development of Ghana‟s science education policies, the use of practical activities, and the use of micro chemistry experimentation as tools in the formation of science concepts, has been explored. There is a section on the examination of some theories of active learning and their impact on practical activities as well as how they facilitate learning. Reviewed are research findings on how microchemistry experimentation and low-cost equipment have facilitated learning in other countries. The singular quality of the micro equipment that facilitates their possible use in all types of schools in Ghana has been discussed. Critical issues arising from this literature review have been considered and implications drawn for the conceptual and methodological features for this study.

## Situational analysis

Students appear to lack the ability to connect among topics, practical activities and concepts in their study of science, especially chemistry. Therefore, science educators try to reform science teaching, especially chemistry education, by introducing laboratory work to facilitate connection among topics and subsequent conception. Most practical chemistry activities are performed on macro scales with large macro glassware equipment, which require time and carefulness, often to the neglect of the concept behind the activity. Standard laboratories require large quantities of chemicals for use, which are often unattainable. New ways are, thus, being sought for the teaching of science to enhance student understanding and to make chemistry lessons more attractive. One of such possible ways is to make science curricula and supply of accompanying practical accessible to all; be it in the rural or urban settings. Methods employed in teaching and carrying out the activities do not often take into consideration the different types of labs: skills lab, process lab and concept lab. The term „lab" as used here implies laboratory activities with science equipment, which are specially designed towards the development of intended outcomes, goals and learning skills (Reid & Shah, 2007). Often, chemistry activities are overloaded as they involve all of these labs as well as high order inquiry questions. This work overload makes it impossible for teachers and students to achieve intended goals in their practical chemistry lessons. Thus, a huge gap is created between intentions and outcomes. Mafumiko, (2006) states that, practical activities are more likely to be effective if they are designed with limited and specified learning objectives for a particular activity that enables the teacher to clearly communicate to students. It should not be necessary to load each and every lesson with all the three types of labs with the same degree of demands, many kinds of activities, and so many objectives. According to Kirschner (2002) as well as Paas, Renkl and Sweller (2003), work assigned to or required of students should be in reasonable chunks that can be accommodated and stored by their memories (minds) for easy access and recall. In this way, less noise is created and concept formation is achieved through the formation of linkages.

Laboratory applications are to help students to present scientific data, improve on their skills of scientific thinking, observation, creative thinking, comment on situations, data collection and analysis, and problem solving (Sahn-Peknez, 2004).

According to Sahn-Peknez, some schools do not carry out practical chemistry activities because of reasons such as absence of chemistry laboratories, insecurity due to dangerous chemicals, crowded classrooms, lack of materials, and cost of equipment. Millar (2004) also confirmed in a similar research on non-performance of chemistry practical activities and found out that the cost of equipment, crowded classrooms and insecurity due to dangerous chemicals were limiting factors for the performance of practical chemistry activities. Altun, Derirdag, Feyzioglu, Ates and Cobanoglu (2009) in addition to the stated limiting factors, identified negative attitudes and incapability to design activities for concept development as additional factors for non-performance of chemistry practical work in schools. In order to be able to set up or design a good practical objective with distinct skills to be learned, besides safety, the three main labs- concept, process and skills- will have to be defined clearly in a teacher‟s goals and accompanying activities.

*Lab* means any formal teaching-learning activity in which students use science equipment (Hanson & Acquah, 2014; Reid & Shah, 2007). Lab teaching is one of the hallmarks of teaching and learning in chemistry. However, there are many questions on whether the great expense of maintaining equipment and high cost of consumables is justified and whether or not many of the aims of lab teaching could be pursued more effectively at a lesser cost in non-laboratory settings, and yet enhance concept understanding. Hanson and Acquah, go on to say that, in laboratory teaching, one can conceptualise activity into three distinct and different roles- the concept lab, the process lab and the skills lab. Generally, labs are expensive in equipment, facilities and teacher time. Yet students must gain knowledge through science activities and their inherent conceptualisation benefits. Teachers anticipate that students‟ understanding of the way science knowledge is generated and validated will increase through practical activities

(Abdullah, Mohamed, & Hj Ismail, 2009). Therefore, new and cheaper ways of generating knowledge through activities, which will not take up too much of the teacher‟s time, must be sought.

Other reviews on the effectiveness of lab lessons, as compared to other ways of teaching to generate knowledge, has cast doubts on the earlier assertion by Abdullah, Mohamed and Hj Ismail (2009). Some researchers argue that science labs do not boost students‟ achievement and concept formation. Thus, the high status given to laboratory activities is unjustifiable. Mafumiko (2006), found that science students could not meaningfully summarise important aspects of an experiment they had just completed. They recalled some of their manipulations but not the central goal of the experiment, its theory or basic methods. Further probe showed that the activity was overloaded and students merely followed hints to complete the activity. This is in conformity with Hanson‟s (2014) findings that students appear to lack the ability to connect among topics, practical activities and concepts in chemistry. These revelations suggest that new ways have to be sought for effective teaching of chemistry concepts, if the „cook-book recipe styles‟ have not yielded the desired or expected results.

Lab experiences are generally superior for providing students with skills when working with equipment. The laboratory-based approach to teaching in chemistry can improve students‟ skills in handling equipment, encourage them to do experiments, stimulate them to do experiments carefully and patiently, and draw their own correct informed conclusions (Kelkar & Dhavale, 2000). Thus, teachers need to be skilled in lab teaching methods. According to Huang (2007) and Mafumiko (2008) some of the main aims of organising practical work for concept development are :

- To arouse and maintain interest, attitude, satisfaction, open-mindedness, and curiosity in science
- To develop practical abilities and skills in using experimental techniques and common instruments and
- To develop conceptual understanding and intellectual ability

Abrahams and Millar (2008), suggested the need for greater understanding of the interactions between learning in the lab and elsewhere. These debates and criticisms have arisen due to weaknesses in the classification of lab goals. Most lab goals are really undefined. Meanwhile, students are expected to learn concept, process and manipulative skills in one single experiment. Labs, however, can be categorised according to their main emphasis as:

- Concept labs- which emphasise on teaching a concept as well as overcoming alternative concepts
- Process labs- which emphasise on exercising intellectual skills needed in generating and validating knowledge and
- Manipulative skill lab- emphasise on learning manipulative skills and psycho-motor coordination

*Concept labs*

According to Mafumiko (2006) concept labs require carefully designed interaction between students and experiments resulting in correction and refinement of student concepts (and alternative concepts). The primary purpose of a concept lab is to teach concepts using hands-on activities often integrated with theory lessons. In the concept lab, students use science process skills and psychomotor skills. Evaluation of concept lab must be specific and must focus on only the skills chosen.

*The process lab*

Process skills are defined as those intellectual skills which pertain to the process of generating and validating knowledge experimentally. Some of these intellectual skills are skills related to the design of experiments, defining of variables operationally, the execution of experiments, analysis of data, graphing, data reduction, designing of tables and making logical conclusions. Antwi (2013) intimated that skills are learned through practice and showed in his research how teachers often prevented students from thinking critically by providing too many hints and answers. Process skills are best learned in real situations; so to develop it, students need to be provided with opportunities to exercise the process skills. He further advocated that when some design is required of students, experiments should allow for variations. Process labs, therefore, should not be copies of text book investigations so that students would not be able to copy answers from books but would be forced to make decisions by themselves. Process labs require open lab experiments with ample opportunity for students to make their own decisions regarding steps, such as design and analysis in the experimentation process. In the process lab, students practise intellectual skills involved in the generation and validation of knowledge. In this lab, the teacher asks students to brainstorm, argue their hypothesis, and design experiments to test their own predictions. Process labs are designed for students to exercise intellectual skills involved in generating and validating knowledge experimentally. Process labs cannot exist without concepts. The Researcher is of the view that MCE could allow for such innovative design of process skills and predictions. The reflective aspect of the MCE would allow students to analyse their own results, draw relevant conclusions, and think about possible limits to generalisations and shortcomings.

*Skills Lab*

All labs require pre-lab skill exercises so that manipulative skills could be mastered before going into process and concept labs. Often teachers assume that students have mastered basic lab skills (Antwi, 2013), but this is hardly the case. Hofstein and Lunetta (2004), Hofstein (2004) and Hanson (2014a), all reported that research into the skills lab is lacking and must be developed. They advocate some form of planned practice to be associated with a superior lab performance. Skills lab is to be viewed as a component which is built into lab sessions, or to be recognised as a specialised activity in its own right (Hanson & Acquah, 2014). Skills labs require students to model and reinforce specific psychomotor skills. The skills lab is intended to teach experimental techniques and use of equipment. Skill labs are often done as pre-lab exercises to enable students to focus on the concept under review. Demircioglu, Ayas and Demircioglu (2005) recommended written reports on activities, paper and pencil tests, continuous observation and manipulative skills tests as some of the kinds of assessment for skills labs.

In view of the above challenges, MCE was considered a good approach for improving the execution of practical activity in the University of Education, Winneba (UEW). This is because the MCE approach has the ability to sequentially explore all the various labs through simple, relevant, and fast concept-based activities. According to Hofstein (2004), appropriately designed practical activities can be effective in promoting cognitive skills, practical skills, interest in chemistry, and interest in knowing about chemistry. Besides providing students with authentic, innovative and practical learning experiences, the MCE has the potential to vary the learning environment and enhance students‟ motivation to study chemistry.

Another observation made from context and baseline analysis was the need to equip chemistry student-teachers with both content knowledge and pedagogical knowledge. Acquisition of an adequate knowledge base, enables teachers to draw relationships for themselves and help their students to interact intellectually as well as physically. The content-knowledgeable teacher is able to engage students on productive „hands-on" activities and „minds-on" reflections (Bradley, 2000). This research work primarily sought to equip chemistry teacher-trainees with the skills and knowledge that they need to develop sound chemistry concepts. In addition it was to equip the trainees with transference skills to help their students acquire scientific concepts when they go out to teach through the use of MCE experimentation. Often, inadequate content knowledge and pedagogy on the part of a teacher could lead to poor explanation which could subsequently lead to the formation of alternative concepts.

Most often, beneath the expressed student alternative conceptions may lay a set of what may be called commonsense concepts, which students may not even be able to articulate, as observed by Taber (2002). This could be likened to what Coll and Taylor (2010) call „paraconceptions". Students can be seen as possessing a large set of *phenomenological primitives* or *p-prims, a* "rich system of elements that are organized only in limited degree and are incoherent …. relatively simple and usually abstracted from common experiences. Thus, their concepts about science phenomena, which occur in everyday life, are often warped. For example, people expect that greater effort is accompanied by greater results or that issues must have direct proportional relationships. Thus, there is the assumption among educators and learners of chemistry that, frequent laboratory practice will lead to increased concept formation. This will not hold true if the designed activities do not lead to proper concept formation. It is proposed that these p-prisms are never discarded but rearranged to form new concepts.

That level of analysis (whether p-prims are rearranged to form new concepts) is beyond this work, but may help explain the observation that groups of students holding alternative conceptions and struggling with discrepant facts can, with guidance and some appropriate questioning, discuss their way into a very different and stable conception through MCE experimentation.

**Location of the study area**

The study was conducted in Ghana, a country which is centrally placed in West Africa. Ghana is bound on the Eastern side by Togo, on the West by Cote d'Ivoire, on the Northern side by Burkina Faso, and on the South by the Atlantic Ocean. Ghana has a population of about 24 million people made up of about 8 million youths under the age of 15 years (Dickson & Benneh, 1988). This is the age group that the government of Ghana expects to study some sciences before entering senior high schools.


**Figure 1: A Map of Ghana**

Winneba is in the southern part of Ghana, and this is the specific location of the University of Education, Winneba. It is the capital of the Effutu Municipal District in the Central Region of Ghana. It has a population of about 58, 750 people. It is a historic fishing town lying on the south coast, 140km east of Cape Coast – its regional capital. It is also known for its academic capabilities because of the large number of educational institutions, such as the University of Education, Winneba, secondary schools, vocational institutions and numerous government and public basic schools. UEW turns out thousands of teacher-trainees who specialise in various disciplines as a result of the diverse number of programmes and courses that it runs. Figure 2 is a map showing the specific location in which the research was conducted.


**Figure 2: A Map showing the location of Winneba**

**Context of the study**

The context of a study in research comprises environmental factors that may influence the research process and or the instructional outcomes under study, including the physical environment, time of day, as well as social and demographic factors. The study of science is compulsory in all basic and secondary schools in Ghana. One of the general aims of science education is that all Ghanaian children must be scientifically and technologically literate by the time they complete a terminal level of their education (Ministry of Education, Science and Sports, MOESS, 2008). All students have to write national examinations organised by the nation"s examinations body, the West African Examinations Council (WAEC) in various science disciplines, chemistry inclusive, for entry into tertiary institutions. An informal interaction with some secondary school chemistry teachers on students" understanding of basic concepts in chemistry showed that students avoid questions requiring deductive thinking; thus, they are unable to go beyond stating definitions due to poor lab skills.

Due to their inability to understand basic science concepts, analyse scientific situations and reason deductively, very few students are able to progress from the secondary to the tertiary level of education, as a pass in science is a pre-requisite for admission into tertiary institutions (PRACTICAL, Final Project Report, 2010). In view of the lapses in the acquisition of scientific knowledge which has been identified, teachers have to be trained and equipped with pedagogical skills to enable them assess and restructure their own personal teaching skills (Kombo, 2006). With these skills they will also be able to develop innovative methods to help their students also develop inquiry minds and scientific approaches to issues in their environment. Mafumiko (2008) showed in a study in Tanzania, where he intoduced the MCE into the educational curricula as a catalyst to improve practical work, that the provision of exemplary teaching materials to teachers could help them to develop pedagogical and content knowledge skills useful for generative and interactive teaching.

**The role of exemplary teaching and learning materials for teachers and students**

Exemplary teaching and learning, sometimes referred to as educative materials (Schneider, Krajcik, & Marx, 2000), are educational resources which clarify and support teaching and learning in educational settings. Examples are students‟ work sheets and work sheets with model (suggested) answers for the teacher, model lesson plans with activities and outcomes and after-class assignments (Schneider, Krajcik, & Marx, 2000). They act as teaching aids which can provide a novice teacher with adequate introductory knowledge and skills for various topics. Curriculum or educative materials, including textbooks, teacher guides and technology-based materials, whether supplied by publishers or researchers, have traditionally been designed with student learning as the goal. However, materials can be designed to support learning by teachers as well as by students. Educative/exemplary curriculum materials are designed to support teacher learning, as the materials are used by teachers to support student learning. Exemplary materials provide clear understanding of how to translate curriculum ideas into classroom or laboratory practice. They also provide, in concrete terms, how lessons which are designed or intended for classroom lessons should be executed. Curriculum materials stimulate reflection on the teacher‟s role and any other adaptations of attitudes towards new ideas in teaching (van den Akker, 2004). Such materials help teachers in a step-wise way of going about a new teaching approach in a friendly manner. In this way, teachers do not get frustrated in their attempt to translate the curriculum in other ways. It also prevents them from going back to the traditional methods they know about. Such materials help teachers and benefit students as well. In the study by Schneider, Krajcik and Marx (2000), teachers reported that using the educative materials helped them to understand the intended instructional practices and science content better. The materials further went on to enhance their pedagogical content knowledge, which was an added outcome in Schneider, Krajcik and Marx‟s research. Curriculum materials have been known to facilitate reforms because they are concrete, tangible ways for embodying the essential ideas of a reform (Powell & Anderson, 2002). Students, who will now be introduced to a new approach to doing activities in chemistry experiments, will also require exemplary worksheets as well as model questions and answers. This will ensure that they approach the new development with ease. Thus, in this study, exemplary curriculum materials were designed, with the different lab skills in mind, to benefit both teachers and students. A prototype curriculum package was produced and trialled for reliability, consistency and validity.

A prototype is a model built to test a concept or process, or to act as a thing to be replicated or learned from. It is built to test and trial a developed design to enhance precision by users. Prototyping serves to provide specifications for a real, working system rather than a theoretical one, and is a useful tool for teacher-trainees. Similar studies involving the development and use of curriculum materials in supporting curriculum reform efforts have been reported (Mafumiko, 2006; Ottevanger, 2001).

Findings from Mafumiko and Ottevanger‟s studies, as well as others, are consistent with those reported by van den Akker (2004), but also provide additional understanding on how teacher-knowledge and transference skills can be improved. The introduction of the MCE in teacher education at UEW would go a long way to give regular training to teachers for the use of MCE when adopted by the Ministry of Education (MOE) and Ghana Education Service (GES) for use in Ghanaian schools. This MCE will be accompanied by the necessary concept-based teaching and learning materials for use by both teachers and students to facilitate its implementation, in accordance with Lewin‟s (2000) recommendation for efficient science teacher training, and the introduction of equipment for use in school science.

**Teacher education in Ghana**

Education is a condition for development and the teacher is the ultimate definer of its reality. The quality of teacher education is critical if education is to enhance development. Teacher preparation, mentoring and motivation are critical factors in enhancing quality education capable of facilitating meaningful development (Adegoke, 2003). Teacher education programme in Ghana is structured to provide:

(a) a three-year pre-service Diploma in Basic Education designated as Basic Education Programme A for teachers at the primary level and Basic Education Programme B for teachers at the Junior Secondary level

(b) degree programmes in various disciplines in education for the Senior Secondary level and all other levels below the senior level.

Teacher Education in Ghana is provided through pre-service training within the context of training institutions programmes, in-service training to improve qualifications in the process of whole school development, and in-service training at school, cluster and district levels, to improve skills, knowledge and competence in the process of whole school development. Primary school teachers generally teach all subjects in a class. Junior High School (JHS) teachers are subject teachers who teach more than one subject. These two categories of teachers could be trained in the Colleges of Education, or Universities of Education. Senior High School (SHS) teachers are subject specialists, who are trained in the Universities or Polytechnics. Tutors for the Colleges of Education (COE) are trained in Universities (Adegoke, 2003).

The major teacher training institutions in Ghana are the University of Cape Coast (Faculty and Institute of Education), University of Education, Winneba, the 38 government Colleges of Education and three private ones in the 10 regions of Ghana. University of Cape Coast and University of Education, Winneba, are the highest teacher education institutions in Ghana. The vision of teacher education in Ghana is to prepare the grounds for quality teaching and learning outcomes through competency-based training of teachers. The mission is to provide a comprehensive Teacher Education Programme through pre-service and in-service forms of training that would produce competent, committed and dedicated teachers to improve the quality of teaching and learning in Ghanaian classrooms (Adegoke, 2003).

The mission and vision of the University of Education, Winneba, have been solely to train teachers with sound knowledge in both content and pedagogy to man all sectors of education in the country (UEW VC's Annual Report, 2013). As at 2009, Ghana had 25 small private universities, and 10 Polytechnics (PRACTICAL, Final Project Report, 2010). None of these recently established institutions train teachers. Thus, the University of Education, Winneba and the University of Cape Coast are the Degree awarding teacher training institutions for all the numerous basic and secondary schools in Ghana. These two institutions train teachers for some of the other tertiary institutions in Ghana as well. It is, therefore, imperative that teacher trainees in these institutions are equipped with new and modern skills of teaching. This will enable them to, in turn, translate the knowledge acquired into highly practical, interactive and knowledge-seeking students, as well as future graduates, who will be part of a cycle of resourceful and innovative citizens. However, inadequate staffing, laboratory and workshop facilities have even limited the capacity of the University of Education, Winneba, in its efforts to train and produce quantity and quality high level science educators and technicians for schools in Ghana.

There are 38 public diploma awarding Colleges of Education which also train teachers. These were formerly designated as teacher training colleges and were under the auspices of the Ghana Education Service (GES). These institutions have a mandate to train teachers to man the Nursery, Kindergarten, Primary and Junior High Schools. The products from these institutions only teach in the basic schools, as they do not have the requisites to teach in higher institutions, such as Senior High Schools (SHS), polytechnics and the universities. Out of these 38 Colleges of Education, 15 specialise in the teaching of Mathematics and Science (Adegoke, 2003). Lewin (2000), found that preservice teachers often get work experience with equipment they are not likely to use after graduation. They are not trained to work with the kind of equipment which is actually in use in schools, or to work with little or no equipment at all. They are seldom taught how to work with local or available materials (Yitbarek, 2012). Lewin went on to add that, often, training is not offered when new equipment is supplied to schools. Although well-prepared manuals and teacher-guides may be supplied, they are frequently not enough to ensure efficient use of the equipment. In-service training is very important when new equipment is accompanied by changes in the curriculum. Thus, it is important that these science teacher graduates learn the best skills and innovations in the teaching of science so that novel interactive ideas of teaching and learning can transcend down the educational ladder. It is hoped that each new learning approach, especially the interactive teaching approach, would enhance students" understanding of chemical concepts and lead to a subsequent gain in cognition. This would also result in a new breed of science educators who would help to break the present vicious cycle of transfer of alternative concepts from one generation to the next.

**The science educator as a medium of change**

Ghana is currently facing a shortage of teachers especially in the areas of mathematics, science and technology. This shortage is particularly severe in rural areas where the number of new teachers needed within the next five to ten years is projected at more than 2,500. This is expected to increase every year until the problem is resolved somehow with a sudden influx of trained teachers from an adhoc training programme (PRACTICAL, 2006). In view of this shortage, the University of Education, Winneba (UEW) and Colleges of Education are stepping up their efforts to recruit and train teachers for the education service. The science teacher educator must certainly have a role to play as an agent of new ideas and methods for students to develop their own correct conceptual frameworks in simpler and faster ways. To put it simply, the science teacher educator must be a catalyst for change. The changes required are both conceptual and cultural. The change must be programmed to remove the African child from excessive submissiveness and over-readiness to acknowledge adult knowledge as the final truth. The changes must empower individuals to transcend the typically over-learned ways of thinking (or non-thinking) about the role of science education, to transform mental models of the roles and goals of students and teachers in the learning environment, and to translate new understandings about inquiry and meaningful learning into actual habits of science practice. In order to achieve this, the science educator has to adopt pragmatic constructivist measures that will ensure that all learners get involved in the teaching-learning process to develop their own scientific ideas.

Research indicates that students who do not engage in the learning process, and show undue submisiveness, often have naive conceptions of how the natural world operates. They cannot extend or apply knowledge in new settings due to their limited understanding of correct concepts. As a result, they do not develop the ability to become self-regulating inquirers. Science teacher educators, therefore, must facilitate their teacher-trainees‟ cognitive departure from traditional models of teaching and learning of science. Such a case will be the need to move away from the use of macro scale apparatus for the performance of macro scale experiments for obvious and acceptable reasons. Another will be a move away from the over-reliance on lecture method and cook-book activities (Altun, Demirdag, Feyzioglu, Ates, & Cobanoglu, 2009), which do not encourage students to be assertive and original in their development of ideas.

Evidence continues to emerge, suggesting that a teacher‟s views of the world, teaching and learning, as well as his/her beliefs about knowledge and intelligence have direct impact on the way they teach (Anderson & Krathwohl, 2001; Pine, Messer, & St. John, 2001). Currently, there is a growing body of evidence suggesting that certain beliefs about learning, intelligence, and knowledge are more conducive to teaching in ways that promote meaningful learning. Teacher trainees, therefore, should take the time to explore, articulate, and analyze their own beliefs on science/ chemistry topics so as to acquire knowledge to promote meaningful learning.

A fundamental role of a chemistry educator would be to get student - teachers to think about their own explicit and tacit thoughts about chemistry education, teaching, and learning. One way to accomplish this is to get students to articulate and discuss their understanding, beliefs and prior science experiences (Hung, 2002). In this way, students learn to develop the habits to probe, challenge, and regulate their own conceptions of chemistry education.

**Concept formation**

A concept is a term that denotes a group of ideas about a phenomenon. However, these notions could differ from one person to another about the same idea. A concept is a mental integration of two or more units possessing the same distinguishing characteristics (Ofori & Dampson, 2011). Concepts are the building blocks of theory: they are rarely formed at random. Ideas, such as molecularity, stoichiometry, polarity, bonding and ionisation, are all concepts. These ideas are formed by first differentiating two or more existents from the others. That is, a learner has to perform certain concrete actions such as laboratory activities, in the case of chemistry, to differentiate and form classes. All conceptual differentiations are made in terms of commensurable characteristics which possess a common unit of measurement. No concept can be formed by attempting to distinguish incommensurable characteristics. A concept can also be described as an image or symbolic representation of an abstract idea (Arends & Rigazio-DiGilio, 2000). Wenning (2008) explained that a concept is a mental integration of two or more units which are isolated by a specific characteristic and united by a specific definition. Again, a concept is a generalization that helps to organize information into categories. It is a process by which a person learns to sort specific experiences into general rules and classes. The human mind is only able to remember or retrieve information more easily only after it has successfully made such classifications.

According to Arends and Rigazio-DiGilio (2000) and Dermircioglu, Ayas and Dermircioglu (2005), the formation of concepts follows a developmental pattern. Arends and Rigazio-DiGilio, describe concept formation as the acquisition of conceptual skills in one‟s cognitive framework. He again indicates that science concepts are mental organisations about the world that are based on similarities among objects and events. This means that concept formation is an interpretation or understanding of what has been experienced, as for example, through an activity or a kind of interaction with the environment.

The process of acquiring and using new concept is described as concept formation. What is of importance in this research is the development of one of the best ways for concept formation and retention, based on students‟ prior knowledge and practical activity. Views of constructivists like Grabowski (2004) and Wenning (2008), with respect to learning, have been reviewed against that of inquiry authors like Bybee, Taylor, Gardner, Van Scotter, Powell, Westbrook and Landes (2006) and Bentley, Ebert and Ebert (2000). Active and generative learning has been proposed by authors such as Ritchie and Volkl (2000), Wimberg and Hollins (2002) and other constructivists. These authors perceive that learning best takes place in an environment where students are subjected to generating their own learning by active involvement. The MCE experimentation has all that it takes to create an environment whereby students will be exposed to activities to find out scientific truths. Activities involving the MCE are simple and easy to carry out in relatively shorter periods. They thus allow time for deliberations on practised activities for further concept formation and reinforcement. More importantly, the design of the MCE- approach fundamentally helps to build concepts through simple repetitive activities. It seeks to avoid overload of cognition in the teaching and learning of basic chemistry concepts. The formation of concepts in the views of these named authorities will be discussed, with respect to the MCE.

In science, and particularly chemistry, students are encouraged to group information and give descriptive labels to their groupings. As they link examples to the labels and explain their meanings, they are able to form their own framework and understanding of the concept. The thinking process helps them to create new and expanded meaning of chemical concepts as they organise and manipulate information from other lessons and contexts in new and less burdensome ways. Concept formation in chemistry has to be active and generative for students to develop sound and lasting understanding in their minds. Some schools of thought opine that children come to school with alternative science concepts of their own, which they may finally abandon for more generally accepted science concepts. On the other hand, some authors regard science learning as a gradual transformation of children‟s pre-existing ideas of daily phenomena they encounter, which are enriched and restructured. This latter conception proposes that children‟s prior concepts are foundations upon which new knowledge is built while the former proposes that children change their prior concepts in favour of accepted scientific concepts. It is clear that learners of science at all stages begin with some kind of pre-existing knowledge. This study set out to explore some of the pre-existing knowledge of teacher trainees engaged in the study of chemistry, and provided an intervention in the form of practical activities to modify their pre-concepts.

**Beliefs about learning chemistry and concept formation**

A concept is an image or symbolic representation of an abstract idea. It is a term that denotes a group of ideas about a phenomenon. Arends and Rigazio-DiGilio (2000) defined a concept as a "complex mental formulation of experience". Concepts are the major components of theory and convey the abstract ideas within a theory, especially in the study of chemistry. Prior to the 1970s, chemistry teaching was dominated by a transmissive approach (Coll & Taylor, 2010). Implicit in this approach was a view that learners came to class with no or very little knowledge of the world they lived in. In line with this, little account was given to students" alternative concepts of chemistry, which were considered to be easily extinguished or replaced by the teacher through persuasive argument. This is now changing as the emergence of learning theories such as cognitive and experiential theories have challenged this passive view of learning. The student was and has since been seen as an active individual who could make sense of events and construct knowledge through experiences with the environment.Chemistry teachers and students are now learning through various methods to construct chemical principles. Cognitive theorists acknowledged the fact that students bring to their chemistry learning, beliefs and experiences about natural phenomena which they have learned to make sense of. Of course, these ideas could differ from expected chemical or scientific views and could be resistant to change if already well grounded. Such thinking led to the development of the constructivist paradigm which has a basic premise that knowledge is created in the mind of the individual rather than absorbed or transmitted from an expert or teacher to a student (Altun, Demirdag, Feyzioglu, Ates, & Cobanoglu, 2009). Again, such knowledge could be useful in the teaching learning process.

**Nature of students' understanding**

Some literature in science education present issues about students" own ideas – formerly called misconceptions (Duit, 2011; Horton, 2007; Taber, 2009). There has been a debate about the nature of learners" ideas in science and whether to describe them as alternative concepts, conceptual frameworks, intuitive theories or mini-theories. It has been suggested that the „misconceptions" imply a misunderstanding of canonical knowledge, whereas „alternative concepts" include notions developed spontaneously, such as those ideas acquired from direct experiences of the world (Tytler & Peterson, 2005). The term misconception also seems inappropriate for those situations where an individual acquires wrong ideas from another. For example, teachers with flawed content knowledge could present incorrect ideas to learners in class (Taber & Tan, 2011). In such a case, learners do not „misconceive" what has been taught but rather may correctly understand the alternative concepts presented. The term „alternative concept" is also sometimes considered to be better fit with the constructivist perspective as Taber (2009) proposes. He considers learning as an active process of personal knowledge construction within each individual. Some alternative conceptions elicited in research seems to be especially significant for student learning. For example, students often adopt a wrong stand relating to the behaviour of matter at the submicroscopic level. They commonly adopt a belief that atoms want to and behave in such a manner to fill their outer shells to obtain an octet of electrons so as to be stable. According to Taber (2006), this idea is an extensive alternative concept used to explain bonding and the ionisation energy concepts. Research has shown that instead of memorising a host of correct details, learners tend to recollect events by incorporating a few details within a schema for an event (Wenning, 2008). Alternative conceptions often result when new experiences are interpreted in light of prior experiences, and new understandings are grafted onto prior understandings. Wenning goes on to say that the origin of a given alternative conception is often difficult to determine. Misunderstanding, miscommunication, and even a misapplication of well-established physical principles lead to the formation of alternative concepts. For example, haphazardly making observations and drawing conclusions from wrong data could lead to the formation of alternative concepts. Improperly designed laboratory activities have been found to be a big source of students" alternative conceptions. Sometimes wrong concepts arise from clinging to false notions from poor teaching, misuse of instruments resulting in unreliable data, over generalisation from data, misinterpretation of graphs, logical fallacies in argumentation and failure to apply critical thinking abilities. Alternative conceptions are not always naïve viewpoints. They could be paraconceptions (Wenning, 2008). According to Gooding and Metz (2011), all misconceptions could be classified as falling into one or more of five categories. They describe these as preconcieved notions, nonscientific beliefs, conceptual misunderstandings, vernacular misconceptions and facutual misconceptions. According to them, preconceived notions are popular misconceptions rooted in everyday experiences. An example is the belief that ground water flows just as is observed with surface water. They went on to describe nonscientific beliefs as those learned from other sources than scientific education, such as from religious or mythical teachings. Gooding and Metz continued to explain that conceptual misunderstandings arise when students are taught scientific information in a way that does not provoke them too confront paradoxes and conflicts resulting from their own preconceived notions and nonscientific beliefs. Vernacular misconceptions result from use of words, such as „melt" which appear to have different meanings in everyday life and scientific context. Factual misconceptions are false ideas which are learned early in life or childhood and carried on into adulthood. Of interest in this study will be conceptual misunderstandings.

In order to minimise the incidence of conceptual misunderstandings, well structured practical activities, as with the MCE approach could ensure that learners form the acceptable scientific concepts through a structured lab-coordinated activity (that is sequenced process, concept and skill labs). From the concept-based MCE approach, learners are expected to gain sound chemical concepts as shown in Figure 3.

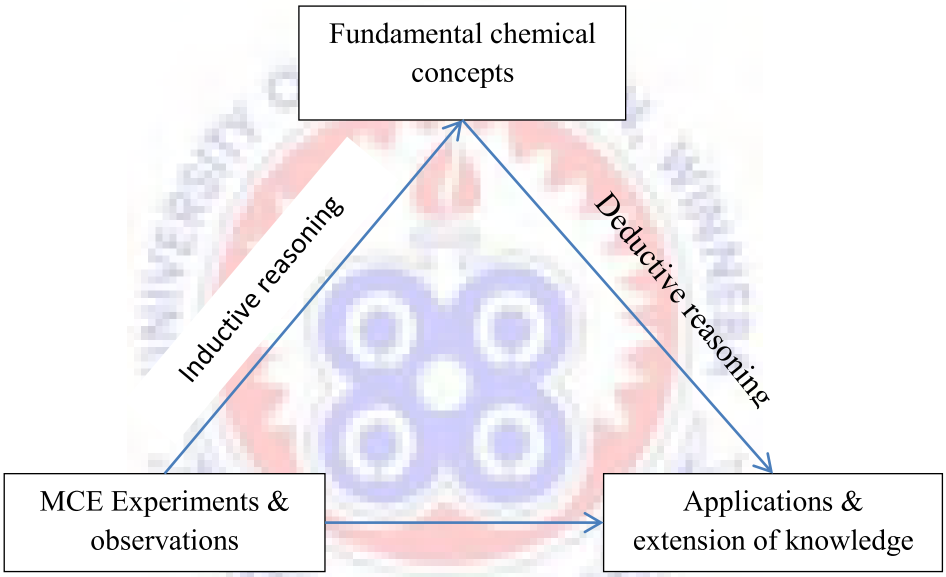


**Figure 3: Concept Formation through MCE-based Activities**

Despite the proliferation of studies into students" understanding of chemistry, there has been relatively little investigation into students" concepts at the tertiary level of chemistry education. In this study, this issue will be addressed by identifying a range of possible alternative mental constructs of basic chemical topics. The MCE will be used as a practical tool to effect conceptual change and resolve any tertiary students" alternative concepts about such basic chemistry topics. Conceptions which tertiary students hold about chemical concepts have been researched infrequently. Perhaps it is because at this level, it may be perceived that they have sound understanding of scientific concepts and are therefore less prone to developing naïve mental models. Yet, the very few research works done on tertiary students showed that indeed tertiary students also have a lot of misconceptions, some of which are hard to change (Coll & Taylor, 2010; Taber & Tan, 2011). Taber and Tan (2011) carried out a research on A Level students and pre-service teachers who had a first degree in chemistry and were training to be teachers in Singapore. The comparison showed that graduate pre-service teachers offered incorrect responses but less frequently than high school students. The teacher-trainees retained high levels of alternative concepts and a few misconcepts were found to be common among them. Coll and Taylor (2010) also made a similar observation in a research on high school and tertiary students‟ alternative concepts in chemical bonding.

It is important to study into students‟ ideas or alternative concepts (ACs) as they play a major role in learning chemistry than simply producing inadequate explanations to questions. Students either consciously or subconsciously construct their concepts as explanations for the behaviours, properties or theories they experience. They believe most of these explanations are correct because they make sense in terms of the understanding of the behaviour of the world around them. Other studies suggest that alternative ideas will effectively block new learning whereas other researchers find alternative concepts act as intermediate conceptions on conceptual trajectories leading to target knowledge (Haider & Al Naqabi, 2008). Yet, other studies suggest that in some circumstances, learners can adopt manifold conceptions of a topic with new ideas, supplementing existing ways of thinking (Taber, 2000). Alternative concepts could be isolated ideas while others could be integrated into theory-like conceptual frameworks

(Taber, 2006). Consequently, if students encounter new and correct information that contradicts their alternative conceptions, it may be difficult for them to accept the new information because it would seem wrong and unacceptable to them. In this case the perceived anomalies would not fit into their conceptual cognitive structures. Under these conditions, the new information may be ignored, rejected, disbelieved, and deemed irrelevant to the current issue, held for consideration at a later time, reinterpreted in the light of the student‟s current theories, or accepted with minor changes in the student‟s previously held concepts. Research may be able to suggest teaching approaches to be avoided or adopted to help channel students‟ thinking in the desired directions for concept development (Edwards & Hammer, 2004). These researches inform science pedagogy (Taber, 2009). Again, tertiary and secondary students exhibit these conceptual constraints due to poor understanding of basic pre-requisite concepts required for a particular topic (Coll & Taylor, 2010). Alternative concepts could result from teaching flaws. Teaching may act as a source of alternative concepts if students are directly taught ideas inconsistent and unreflective of target knowledge, either due to misjudgments in teaching models used (Justi & Gilbert, 2000) or flawed teacher knowledge. Canpolat, Pinarbasi, Bayrakceken and Gehan (2006), reported Indian teachers as having widespread misconceptions on the topic of chemical equilibrium. It is widely reported that teachers‟ actual subject knowledge is inevitably imperfect and that even inexperienced teachers potentially have much to learn about topics they teach (Wenning, 2008). Reviews from literature confirm that teachers‟ own alternative concepts make up a significant factor in the development of some alternative concepts among students. It is therefore important to use seemingly corrective measures to enhance scientific construction of chemical concepts among students (especially teacher-trainees) so as to break the vicious cycle of transfer of misconcepts. Students‟

strategies and conceptual frameworks which they may exhibit in trying to understand a new situation has been examined in the next section.

Two types of information processing have been identified in literature- these are surface and deep processing (Chin & Brown, 2000). Learners who engage in surface learning are found to memorise and reproduce the learning content without analysing them. This group of students do not break down the tasks given them into little bits so as to tackle them on sectional basis for effective analysis. On the other hand, students who adopt deep learning approach to studies, by forming concepts from their activities, have been found to structure the learning contents and engage in relating them, while in a critical processing manner, try to relate learning to real life situations. This group of students strive to understand the learning content and make effort to link new information to previous knowledge. Adapted micro chemistry activities tend to allow tasks to be broken into pieces for repeated practice, effective analysis and concept knowledge development. The MCE concept-based activities are structured upon both the experiential and cognitive teaching and learning theories which allow for deep processing of information.

The development of conceptual knowledge is important in chemistry learning. Students῾῾ chemistry concept formation is crucial for the development of self-confidence and becoming seasoned scientists. Conceptual knowledge helps to build students῾῾ reasoning power and decision- making ability. The Senior High School Chemistry Syllabus (CRDD, 2006) requires that students engage in practice-oriented activities so as to develop appropriate science concepts that can be applied to solving practical life problems. However, the processes by which conceptual changes occur have remained controversial as shown by the two opposing views which appear to feature in this review.

**The significance and impact of practical activities on concept formation**

Practical work is considered as one of the processes by which students‟ science concept formation and transferable skills may be enhanced and applied in future life (Reid & Shah, 2007). According to Herrington and Nakhleh (2003) practical activities singularly or jointly (with other modes) facilitate conceptual understanding. This is because science practical activities allow students to change their initial understanding of scientific concepts through the creation of association, similarities and confirmation of distinctions. Such innate conceptual understanding through practice enables students to gain a better understanding of their environment and even apply their knowledge gained in new situations. This implies that students who engage in practical activities to gain understanding of scientific concepts are likely to apply them in their daily life activities. It also implies that students will be able to apply the knowledge they have acquired to novel situations. Practical activities, as a form of instructional strategy, thus help students to increase their understanding and application of many phenomena around them through practice.

The idea that meaningful learning is possible during chemistry practical activities, if students are given opportunities to manipulate equipment and materials in a suitable environment, is widely accepted, but research in didactics has not found simple relationships between laboratory practice and the learning outcomes of students (Hofstein & Lunetta, 2004). Tortosa (2012) added that the chemistry laboratory is a unique learning environment as it has the potential to provide chemistry teachers with opportunities to vary their instructional techniques and to avoid monotony in the learning environment. Tortosa went on to say that although it has been demonstrated that traditional teaching methods do not solve students‟ learning difficulties, there are various opinions on how to teach or how to apply the results of research on science education into school laboratories. Meaningful learning is said to take place when students do not only remember facts, but are able to apply what has been learned in diverse ways, such as in practical activities. Considerable amount of research by Anderson and Krathwohl (2001) on science teaching and instructional methods showed that lectures have not been effective in the transfer and acquisition of credible scientific knowledge. Sufficient data however exist to suggest that laboratory instruction is an effective and efficient teaching strategy to attain some of the goals for teaching and learning chemistry and that appropriate laboratory exercises have a great potential to provide students with opportunities to develop skills regarding science communication (Hofstein & Mamlok-Naaman, 2007).

According to some instructional theorists, (Ritchie & Volkl, 2000; Wimberg & Hollins, 2002), instructional strategies have a variety of effects on learning. They assert that the amount of cognitive load placed on a learner is dependent on the strategies being used to present instruction. Clark, Nguyen and Sweller (2006) have found that the different strategies used to present instruction may not have a common effectiveness on the learning process unless the learner has through repeated practice or the identification of patterns discovered a way of sequentially arranging ideas. It is therefore left to the learner to develop a pattern of rules (schema) that links the learning process to the instructional strategy. Gerjets, Scheiter and Catrambone (2004) have also found that there are two main processes by which learners develop their schema-either through regular practice or by studying examples. The current study is embedded in the use of the two processes where the instructor demonstrates for the very first time (example) for students to take a cue from and also from practice where students are given practical activities to perform repeatedly over a period. This micro chemistry approach which involves practical work is therefore expected to help students to build strong information processing strategies (mental) and help their understanding of scientific concepts.

Science practical or laboratory activities have been known to help in the understanding of abstract concepts (Horton, 2007). They play a very significant role in the understanding and correcting of students‟ own ideas. They also help students to develop observational skills, explain certain concepts well, have a good experience of what science is all about and gain basic laboratory skills. Some of these aims have remained unchanged over the years. Watson (2000), and Bennett and Kennedy (2001) categorize some aims as to be able to:

- develop manipulative skills and techniques
- discover a concept, law or principle or illustrate it in other innovative ways
- motivate by stimulating interest and enjoyment
- develop understanding of experimental procedures such as open-mindedness and objectivity (that is science research skills)
- encourage accurate observation and description
- experience a scientific phenomena
- get a feel for what it is like to be a problem solving scientist

Yoo, Hong and Yoon (2006), add other goals which include stimulation of creativity, self-motivation, recognition of relevance of scientific understanding and independent thought.

Sometimes there is a little confusion as to the effectiveness of practical science worldwide as researchers have varying expectations based on where they are coming from. Hawkes (2004) has challenged the place of practical activities in higher chemistry courses. He argued that the evidence of chemistry trained students did not support the idea for which laboratories were set up. He noted that the enormous expenditure of time and money, coupled with students‟ dislike of laboratory work was not worth all the efforts put into teaching practical work. Considering that only half of his research sample was uninterested in practical work and about half did not practice it, the teaching of laboratory work cannot be disregarded because half of a student population will still make good use of the intellectual, transferable and practical skills that will be gained from practical work.

Some of these different opinions on the importance of practical work have emerged because different activities coexist under the umbrella of practical work. Some other practical activities may be extreme short worksheet laboratory exercises while others may be long open-ended student-driven projects to equip students with transferable skills as in the case of teacher-trainees. In all of these confusions, the essential fact remains, that performing activities have beneficial results for both the teacher as well as the student if structured with care and performed in line with objectives to ensure proper understanding of basic principles and concepts.

Scientists all over the world agree that practical work increases comprehension of scientific principles (AJCE, 2012). Comprehension of these principles allows for their applications in our daily lives, especially in the transfer of concept understanding to new situations when learning. Almost all modern teaching methods emphasise the hands-on and minds-on approach to teaching. There is currently a change from the traditional acquisition of knowledge to scientific inquiry, problem solving and application of science. The most effective and relevant learning takes place through the fundamental process of *doing* to solve problems as proposed by Kolb, Boyatzis and Mainenlis (2001) and constructivists such as Dewey, Piaget and Vygotsky. Thus in the absence of practical activities, students will not gain any better understanding than they did during the era of lecturing and blackboard demonstrations by the teacher (Hanson R. , 2014a). It is therefore expected that opportunities would be created for students to engage in as much practical activities as possible to enable them form their own correct basic concepts in chemistry.

In most of the schools in Ghana, practical activities do not appear to be accorded the prominence they deserve. Perhaps this situation may be blamed on limited science equipment in the schools for organising effective science practical activities. Due to limited resources the purchase of standard equipment may be too expensive for most schools in Ghana. Furthermore, some schools may argue that the replacement of used chemicals and broken glassware may be unbearable due to their financial situations. In order to overcome all these, this study suggests the use of MCE which has been known to be far less expensive and would be within the reach of most under-resourced schools in Ghana. Micro chemistry, in general, is the development and use of techniques and equipment to study or perform chemistry reactions with very small quantities of materials, often less than a milligram or a millilitre. The robust micro equipment are packaged in kits and can be used without fear of massive destruction of the various components. Also, a wide range of experiments suitable for the schools, such as analytical, qualitative and quantitative determinations could be carried out with the micro equipment. If the kits are put to use as expected, it is hoped that the development of science (chemistry) concepts in Ghana, West Africa and the whole of developing Africa would go a long way to enhance the technological advancement of industries and enterprises as well as the general development of the African.

**The role of MCEs in science concept formation**

The main purpose of MCE is to use drops of chemicals to perform and observe chemical reactions. The activity is done hands-on by each individual. As small amounts of chemicals are used they are affordable and less dangerous to students. In addition, when students use research based lab/work sheets and suitable guidance, they give more priority to focal scientific concepts than to the equipment that they have to use, especially when they are as simple as MCE. Thus students attach more importance to the chemical concepts than to the MCE technology. MCE activities enable students to use their higher-order thinking to understand complex concepts and processes. For example, in teaching stoichiometry in acid base reactions, students get to see the relationships of reacting species by volumes of quantities of chemicals used in chemical reactions. Again, in metallurgy, students learn to extract gold from its ore, using an analogous system, using copper, which is less harmful and easier to handle. They may then have to deal with a focus question such as *How can gold salts be removed from their solutions using charcoal*? Such a question often gets students excited and could take very little time for answers to such a question to be worked out. Most of the MCE focus questions are related to real issues in the environment so as to give a „human face" to the concepts to be studied. Tasks that students have to engage in are contextualised to resemble real-world situations as a form of motivation as well as a ground to allow the transfer of knowledge and skills. The process of MCE activities could be likened to the predict-observe-explain (POE) teaching strategy. In MCE lessons a problematic question or situation (hereby called focus question) is presented to students at the beginning of an activity. They have to recall their prior knowledge or concepts to begin the MCE activities. They make predictions about the expected outcomes and carry out activities to see if it matches with their final MCE outcomes and if their line of reasoning holds true. In a nutshell, students in MCE concept-based learning follow a cycle of exploration, introduction to concepts, structuration and applications to new situations and a confirmation or rebuttal of ideas. There are a few studies about the effectiveness of the MCE concept-based approach to teaching and learning of chemical concepts and competencies. Though MCE has been applied at all levels of education, most studies have been in its use for motivation in secondary science education (Kelkar & Dhavale, 2000; Bennet & Kennedy, 2001; Huang, 2007; Mafumiko, 2008; Zakaria, Latip, & Tantayanon, 2012).

MCEs have been known to provide opportunity for the practice of science (chemistry) for learners. Such positive experiences have been reported from its practice at all levels of education in countries such as Ethiopia, America, United Kingdom, Ghana and South Africa (Bradley, 2001; Yoo, Hong, & Yoon, 2006; Bell & Bradley, 2012; Yitbarek, 2012; Hanson, 2014b). In Mozambique, MCE has been used in Junior High schools and Teacher training institutions to facilitate the understanding of science and chemistry concepts respectively. They have also been used in tertiary institutions to enhance concept development. England, China, India, Malaysia, Turkey, and some African countries have successfully used the MCE for positive effects among undergraduate students (Bradley, 1999a; Singh, McGowan, Szafran, & Pike, 2000; Huang, 2007). In Universiti Kebangsaan, Malaysia, microscale equipment was used as the main tool to improve the quality of organic chemistry (Zakaria, Latip, & Tantayanon, 2012).

**The paradox of science equipment in Sub-Saharan Africa**

The teaching of chemistry in Africa has been dominated by theoretical lectures and that has been limiting students‟ understanding of the various chemical concepts and principles. Such an approach coupled with the abstract nature of the subject interferes with students‟ creativity and innovation capacity. In addition, most African countries do not have the financial capacity to equip schools and colleges with the needed equipment and materials to teach chemistry as a practical enterprise. One way to deal with this paradox is to build the capacities of chemistry teachers and teacher educators in the design and development of low-cost educational tools from locally available materials. Many teachers, however, do not want to build their own science resources for lack of confidence, accuracy and technical know-how. Many African countries have been receiving equipment donations for improving science education for years. According to World Bank discussion paper (Lewin, 2000), large investments have been made to improve the teaching of science in developing countries yet, their effect has been in many cases far less than expected. The main reasons mentioned for the lack of success despite huge investments are: technical unsuitability of the equipment, educational unsuitability of the equipment, faults in the procurement procedures, high cost of the equipment, lack of teacher and technician training, lack of incentives to use the equipment, faults in the distribution, inadequate supply of consumable materials, and inadequate maintenance, repair and replenishment Science equipment has been sent to Africa in the past decades for scientific and technological development, under various sponsored programmes such as the United Nations Development Programme (UNDP), United States Agency for International Development (USAID), Overseas Development Administration (ODA) and United Nations Educational, Scientific and Cultural Organisation (UNESCO). However these programmes failed to achieve their desired goals because the equipment were either not used (stored away) due to their complex and/or sometimes fragile nature or wrongly put to use or misused (AJCE, 2012).

Lewin (2000), in a World Bank report asserted that practical work in science teaching requires special, but often simple, equipment and facilities for effective teaching in Africa. He found out in his analysis of the science equipment situation in Africa that world organisations such as UNESCO, UNDP, IUPAC and GTZ had made supplies to Tanzania, Zimbabwe, Kenya, Uganda, Gambia, Ghana and Senegal.

However, they were not very useful and were not used in some cases as they were inappropriate for the needs of their country‟s curricular. Some researchers into the supply and use of science equipment in Africa (Lewin, 2000; Ottevanger, van den Akker, & de Feiter, 2007), found that in some successful World Bank science equipment supply projects, the equipment were not used at all. It was even possible to find 20 years old equipment still in their original packages in some communities. Yet, most African communities (including those who had stores of unused and potentially dangerous chemicals) still talked about lack of resources for science practical activities. He found that hazardous chemicals such as ammonia dichromate, iodine crystals, copper sulphate and potassium permanganate which are not in high demand in school science had been supplied in very large quantities to Zimbabwe, causing a high risk situation in the science laboratories. Yet other basic chemicals which were in high demand for common activities like hydrochloric acid and sodium hydroxide were in short supply. Thus an apparent lack in the midst of unnecessary plenty was created- a paradoxical situation.  At the same time, other secondary schools had large stocks of phosphorus, sodium and potassium, which are hardly used for high school activities. Ottevanger, van der Akker, and de Feiter (2007), asserted that the high cost of equipment prevents their use and so are safely locked up in schools. He suggested a country- and school-specific approach in the distribution of equipment and consumables to countries and schools. Some other reasons assigned to why equipment are stored so that an apparent situation of lack is created are the educational and technical unsuitability of the equipment, cumbersome procurement procedures, teacher training, supply of consumables and lack of incentives to pioneering teachers of projects.

The desire to introduce the use of low cost equipment or MCE in schools in Ghana may not have to suffer any of these impediments and may never fail due to the nature and versatility of the micro chemistry equipment being introduced for practical activities. The equipment are very simple to use and do not require special training prior to its use. Since very minute quantities of chemicals are required, their supply will last for extended periods before they run out. Accompanying support materials will also provide clearly defined ways of translating the accompanying MCE curriculum into classroom practice. It will in addition, provide in a vivid way how designed MCE classroom lessons would have to be executed. They would stimulate reflection on the teacher‟s role and any other adaptations of attitudes necessary for the innovation. These provisions would be in line with Van den Akker‟s (2004) principles of innovation. The accompanying MCE materials would teach teachers a step-wise way of going about the new approach; thus, no obstacles would be in the way of this new intervention to halt its practise in schools. The curriculum materials would prevent the teachers who use the MCE from going back to their old traditional ways of teaching. The said curriculum materials would directly benefit students as well. Teacher-trainees would be provided with simple to understand worksheets which are also structured towards concept development. Furthermore, they would be able to photocopy the worksheets or be supplied with extra copies which they can use during their own teaching in schools after completion of their programme in the University. Through the continuous use of the MCE, which would be facilitated by teachers and teacher-trainees from the University of Education, the role of practical work as a tool for concept formation would thus become a reality. Though fully equipped laboratories are essential, they are not always necessary for conducting chemistry practical work (UNESCO, 2003). It is important to align the facilities and supporting materials with the curriculum requirements. Through the acquisition of transference skills trainees would be able to improvise low-cost equipment from their locality in times of scarcity for experiential concept-based teaching in their work places. Although modern text-books and curricula are geared towards discovery learning, the case is not always one of a particular modern text book solving the problem at hand. The designed curriculum materials which accompany the MCE ensure that they are commensurate with the needs of an institution‟s curriculum and desired activities. The low-cost MCE would no doubt be a useful beneficial tool for concept change development in the face of lack of equipment for especially, rural schools.

**Versatility of the Micro Chemistry Equipment (MCE)**

The micro chemistry equipment (MCE) is a small set of laboratory equipment used for practical activities. It comprises a special microwell plate (hereby called the comboplate), some specially designed items such as lids for the wells to facilitate the preparation and use of gases and standard items such as plastic syringes and propettes. The propettes could be used as droppers or measures. Included, is a micro stand which serves as a clamp stand, micro spatula for fetching solids and other resources for performing experiments on electrochemistry (Bradley, 2000). Figure 4 is a picture showing some of the typical equipment in a micro kit.

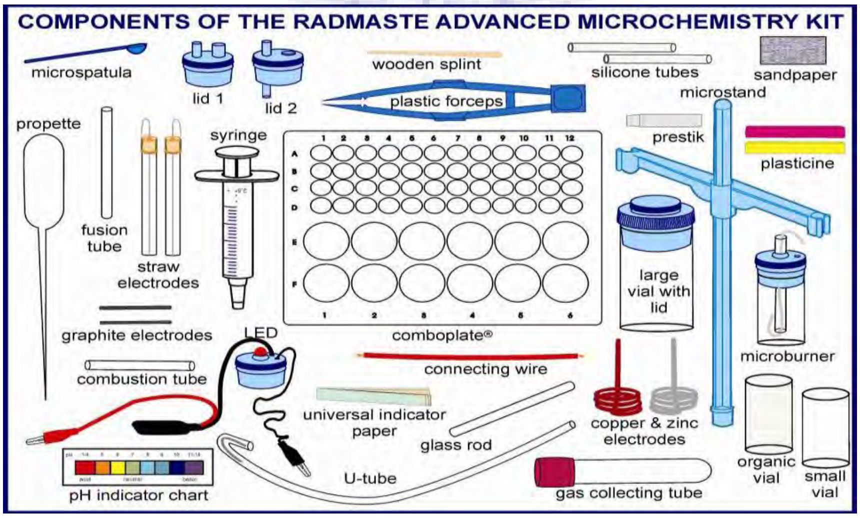


**Figure 4: A Picture of a typical MCE Kit**

The MCE kit performs virtually the same functions as the conventional or standard laboratory glassware for analytical, qualitative and quantitative school laboratory activities. They have been used in schools in South Africa, Kenya, Ethiopia, America, Australia and Malaysia for both qualitative and quantitative chemical analysis (Tallmadge, Homan, Ruth, & Bilek, 2004; Ibanez,, 2012; Sileshi, 2012). Microscale chemistry is an approach to overcome some of the problems associated with macro scale practical work. The MCE provides hands-on activities and personal experiences for learners of science, using reduced amounts of chemicals. Methods for engaging in chemistry experiments are moving toward the semi-micro, micro, ultra-micro and sub microgram preferences for various reasons such as for the purposes of reduction of waste products so that our environment could be preserved and for safer work environments. There have been reports of how school laboratory activities have harmed learners of chemistry in America, even to the point of death, because they got hurt in a simple laboratory explosion during a routine class activity (Benderly, 2010). Other reasons for the adoption of small scale chemistry activities are for faster achievement of experimental results and longer reflection and discussion times, which often result in sounder formation of science concepts (Hanson & Acquah, 2014). Small scale activities, further save cost since sub-micro methods require approximate minimum sizes of 10 mg, micro methods require 1 mg, ultra-micro methods require 0.001mg and sub microgram methods, 0.00001 mg. Meanwhile, macro methods require the use of macro equipment which uses weights of 1 g and above. Balances for the indicated weight and methods are available. Macro balances are under a constant load of 160-200 g, readable to 0.1 mg. Semi micro balances have a range of about 30 g, readable to 0.01 mg and sensitive up to 0.001 g or 1µg, while micro balances weigh up to 1µg. Ultra micro balances are sensitive to 0.1µg or less (Christian, 2004). Precision or accuracy of activities is not compromised. The micro chemistry pack is very versatile. It could be used in other areas of science, besides chemistry. It has been known for use in laboratory activities in the Basic, Junior and Senior High Schools and the Universities. Kelkar and Dhavale (2000) reported that undergraduates performed activities with more care and their skills in handling equipment were markedly improved after adoption of the microscale technique in their laboratory. MCE could be used in clinical as well educational environments for science research and experiments. It may also be used in analytical chemistry, which is a branch of chemistry that deals with detection of substances through precipitation, colour and smell. That is, micro equipment could be used for qualitative work. Again, it could be used for quantitative work as in the determination of amounts of given substances under study. Teachers can also use it as a tool to design new laboratory activities to enhance deeper concept understanding of chemistry topics (Tallmadge, Homan, Ruth, & Bilek, 2004). The basis for using MCE for good concept formation is that it affords students the opportunity not only to do hands-on and mind-on activities but to repeat each activity several times over at very little cost for enhanced conceptual understanding and its reinforcement (Huang, 2007; Zakaria, Latip, & Tantayanon, 2012).

MCE experimentation and its use for conceptual understanding have been in existence for some time in both some developing and developed countries. Although traditional laboratory glass equipment has its advantages, nevertheless, its delicate nature as well as high cost prevents many institutions from acquiring the necessary glassware. Those who may be able to obtain the appropriate equipment may not be able to afford its maintenance and the necessary quantities required for use in their schools, due to cost. Sometimes the purchase of chemicals could be another hindrance even in the face of existing equipment. Thus, MCE is useful in a developing country such as

Ghana and in UEW in particular, where students are being trained to go out to teach sound science concepts through practical activities using improvised low-cost equipment. All in all, the MCE is cheaper than the traditional glassware found in a standard laboratory. These positive attributes of the MCE will thus, enable the expansion of the laboratory experiences of students in large classes and introduce laboratory work into institutions too poorly equipped for standard-type laboratory work. According to Abdullah, Mohamed and Hj Ismail (2009), with the microscale approach, students should be able to improve their understanding of concepts and attitudes towards chemistry as well as laboratory work. Abdullah, Mohammed and Hj Ismail (2009) used MCE in Malaysia to investigate whether MCE experimentation could increase students" understanding of chemistry concepts. Participants in Abdullah, Mohamed and Hj Ismail"s Malaysian study showed an increase in their development of chemistry concepts and reported that they gained a greater understanding of chemistry concepts by doing MCE experiments. They added that they had the opportunity to see chemical processes and products of experiments. All the participants in the Abdullah study agreed that the MCE approach facilitated their understanding. They added that their interest in chemistry also increased dramatically. MCE was equally used in Mozambican Junior High Schools with positive outcomes. Pioneering development in MCE experimentation area was carried out by Mafumiko (2006) in Tanzania, El-Marsafy, Schwarz, and Najdoski (2011) in Egypt, Bradley (Bell & Bradley, 2012) in South Africa, and Ozem (2004). The history (background), advantages, as well as disadvantages of the MCE have been discussed in the subsequent literature.

**Low Cost Equipment as a solution to the lack of equipment**

The provision of equipment or resources for the teaching and learning of science, especially chemistry is very important to enable students" gain a first-hand experience and understanding of concepts. Improvisation of science equipment has been advocated over centuries in institutions and deprived communities where science resources are scare but it appears teachers always find the contribution of improvised equipment cumbersome and time-consuming. However, access to sophisticated, delicate standard/conventional equipment is difficult and expensive for deprived communities (Yitbarek, 2012). The science syllabuses at all levels of education in Ghana emphasise the importance of teaching science from a practical point of view for concept development. Yet, the rising cost of laboratory equipment and chemicals makes the practice of science, especially chemistry, difficult for deprived schools in Ghana. Thus, some students are unable to acquire the basic scientific skills expected of science students. As a result of the lack of equipment and chemicals, the teaching of science in most rural settings in Ghana is done mainly through the lecture method and so students learn facts through memorisation. In this technological era memorisation of inexplicable facts are no longer tenable.

Low cost and simple equipment could be a good alternative to avoid distractions which accompany mastery of sophisticated equipment. Low cost, simply designed equipment is not necessarily synonymous with second-rate equipment or education. In the same vein, sophisticated equipment does not imply mastery of science concepts. According to Kombo (2006) and Mafumiko (2008), it is possible to design low cost equipment (such as the MCE) which are relevant to students and also lead to better conceptual understanding. Many types of equipment can be developed at low cost and still retain the precision needed with their use for school science. They assert that sophisticated equipment could lead to confusion and be a hindrance to science concept formation for students. Based upon the benefits of simple equipment, small scale equipment is being introduced in developing countries for these and several other reasons. Mafumiko (2006) indicates other reasons for using simple, miniature equipment such as for prevention of environmental pollution (less waste chemicals), laboratory safety, and the reduction of cost of chemicals for experimentation.

South Africa, Egypt, Tanzania, Zimbabwe, Sudan and recently the Gambia have embarked on the use of small scale science equipment in schools (Bell & Bradley, 2012; Engida, 2012) to enhance the teaching and learning of science, apart from the environmental benefits and savings. Other countries like Tanzania, Cameroon, and Mozambique are all on board the micro scale or microchemistry project. Micro scale materials are also used in Malaysia, Sudan, Russia, U.K, Angola, Ethiopia, Namibia, The Netherlands and other countries. As global finance goes into greater difficulties and the world population increases, the original concerns (cost, safety and environment) that promoted early interest in micro chemistry remains and is strengthened (IUPAC, 2000).

Based on Ghana‟s history of difficulties with the purchase, maintenance of science equipment, and training of staff, it would be in our own interest to introduce and embrace the use of micro science equipment in our schools for enhancing conceptual change development in chemistry education.

**Chemistry practical activities**

Chemistry is a practical subject and so there is the need for laboratory work. Laboratory applications are major parts of chemistry lessons and complementary to theory sessions. They are crucial for making abstract chemistry concepts concrete and comprehensible (Wellington, 2007). In a critical appraisal of the role of laboratory practical work by Abimbola (2001), the objectives of using laboratory work in science are the teaching and learning of skills, concepts, cognitive abilities, attitudes and understanding the nature of science. All science curricula in Ghana list practical activities that should go with each curriculum item listed (Ministry of Education Science and Sports, 2008). Chemistry practical work should aim at encouraging students to gain transference skills, manipulative skills, observational skills, ability to interpret experimental data, ability to plan experiments, gain interest in the subject, enjoy it and have a feeling of reality for the phenomena talked about in theory. In chemistry education, distinct styles of laboratory instructions expository, inquiry, discovery, and more recently, problem-based such as have been in evidence. Many researchers have reported that laboratory experiences can improve students‟ interest in chemistry and personal involvement promotes their understanding and formation of chemistry concepts (Okebukola, 2000; Hofstein, 2004). Bradley (2001) and Taraban, Box, Myers, Pollard and Bowen (2006) propose that practical work should involve active student participation in order for them to gain more content knowledge and knowledge of process skills. Taraban et al. found that for two topics in high school biology, students gained significantly more content knowledge and knowledge of process skills using active –learning labs than in traditional instruction. The current study used Micro Chemistry Equipment (MCE) for three pedagogical reforms. It sought to provide more and varied opportunities (through experience) for laboratory inquiry, emphasis on critical thinking and proper concept formation in the acquisition of sound chemical knowledge. According to Gerjets, Scheiter and Catrambone (2004), student-centred practical activities which are characterised by inquiry and discussion of open-ended questions are expected to be more effective for promoting deep understanding of science and subsequent concept formation. Their assumption is that changing the way practical science is taught will result in higher average science achievement for all students and decrease gaps in achievement between more and less advantaged groups of students. It is envisaged that the micro equipment will help to decrease the science achievement gap between endowed and deprived schools and communities, since it is cheap, simple to handle, non-breakable and versatile for almost all science and chemistry reactions for the basic and senior high school science topics and activities and requires no formal lab.

Findings from studies by Abdullah, Mohammed and Hj Ismail (2009), Bell and Bradley (2012), and El-Marsafy, Schwarz, and Najdoski (2011) also emphasise that chemistry practical activities enhance ideas gained form theoretical exposition. Reid and Shah (2007) go on to add that the chemistry laboratory practice course must be seen as a whole and the experimental experiences introduced to develop outcomes that will enable students to form concepts. They intimated that pre-lab draws out learners" prior experiences and ideas and sets the scene for the actual laboratory work. The student now knows and understands more of the purpose and nature of the laboratory experience ahead. Laboratory manuals need to be shortened considerably and students encouraged in planning the actual experiment, and understanding why they are doing what they are doing. This would enable them to develop their process and concept skills. Greater open-endedness would be helpful and students would be found to respond to process and concept skills development most positively. They concluded that to ensure the development of the process and concept skills among students" during chemistry activities, there needs to be more emphasis on the process of thought and enquiry and much less on getting a „right" answer especially during the pre-lab.

The post-laboratory experience also through careful planning enhances process and concept skills development. In a study by Hanson (2014a), imaginative post-laboratory exercises were used. These allowed trainees in the study, the opportunity to apply the ideas they had learned, as well as offering some insights into their understanding. These findings are similar to what Bradley (2000) also found out in similar studies. Their findings include among other things enhancement of student laboratory skills and more focus on understanding of concepts rather than the manipulation of equipment, if the equipment are simple. They stress on more time for questions, discussions and feedback as some benefits to be gained from the use of simple equipment such as MCE. In MCE experimentation, underlying ideas are readily understood, experiments are safer to carry out, creates less waste and students find them easy and fun to use. Time spent on activities is also very minimal. Activities are not overloaded with many goals, which could lead to cognitive overload for teacher-trainees. Although the MCE would be appropriate for adoption and use in a country like Ghana and especially in the University of Education‟s Chemistry Department in particular where human and material resources are inadequate, teachers must first be trained to acquire skills for designing lab activities. The MCE or other low cost equipment would afford an opportunity for students to engage in effective and active learning. The framework in Figure 5, discusses the usefulness of MCE practical work and how to determine its effectiveness in concept development.

**A framework for considering the effectiveness of MCE Practical work**

A conceptual framework could be suggested when a researcher links concepts from literature to establish evidence to support the need for designed research questions (Krathwohl, 2009). These could subsequently lead to a theoretical framework, which will be discussed later. According to Abraham and Millar (2008) an experiment particularly in philosophy of science, is generally taken to mean a planned intervention in the material world to test a prediction derived from a theory or hypothesis. Many school science practical tasks, however, do not test predictions derived from hypotheses; thus the term „practical work‟ will mostly be employed for student laboratory activities. While many practical lessons are undertaken in specifically designed and purpose-built laboratories, the type of activity this study is interested in is characterised by using micro equipment in any kind of learning setting to enhance understanding.

The study investigated the effectiveness of MCE designed activities in enhancing concept understanding. To develop an analytical framework, the study began from a model of the processes involved in designing and evaluating a concept based-practical task (See Figure 3). This design was adapted from a model of the processes involved in designing and evaluating a practical task proposed by Millar, Le Marechal and Tiberghien (1999). Figure 5 shows the framework for understanding the effectiveness of practical work with the MCE approach.

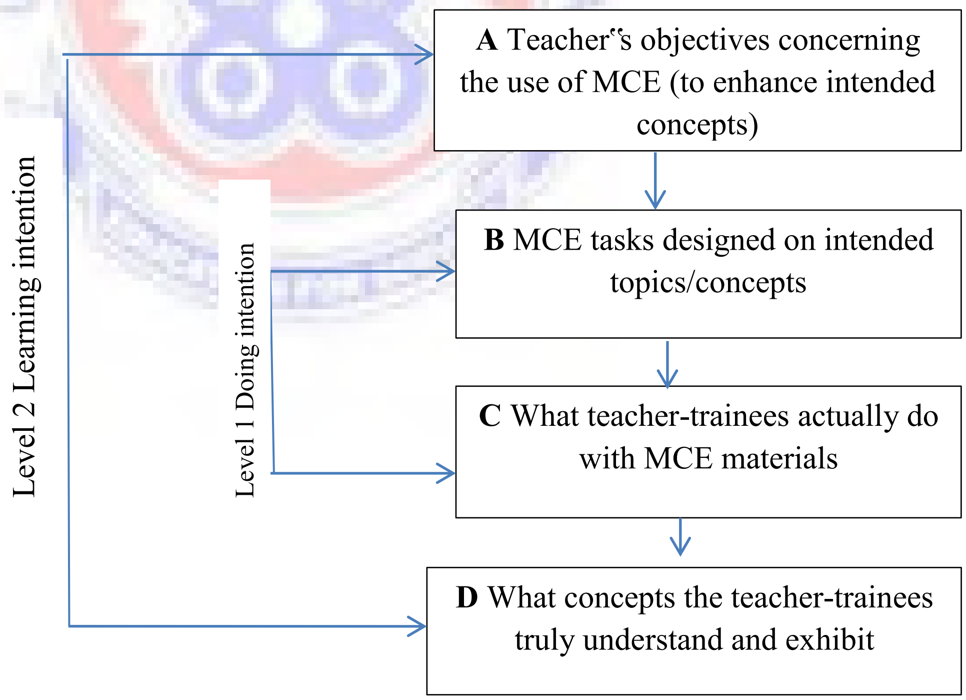


**Figure 5: A model for the process, design and evaluation of MCE-based tasks**

The starting point A, in figure 5, is the broad objective for the use of the MCE and the specific intended concept development or to be developed. The box contains all the defined processes and resources that the teacher will have to put together to achieve her aim or intention. It involves the collection and analyses of teacher-trainees" activities and behaviours. In Box B, the designed selected practical tasks that enable the trainees to achieve the desired objectives are organised or implemented. Box C, questions what the students actually did in the tasks using the MCE materials. This question is always necessary, as what may be intended by a researcher could differ from the actual activity, if students fail to understand the instructions or do not do as is expected of them according to the way the MCE should to be used. Apart from understanding instructions and faulty equipment, it was also possible for students to have initial prior erroneous ideas about the concept which they could work towards. Thus, C, was necessary to ensure that teacher-trainees" mental actions matched their physical actions. Time spent on the use of MCE and attainment of results was measured by what the students" learned at the end of a topic or lesson. Model box D was concerned with what the students learned as a consequence of using the MCE.

What the Researcher intended to do and what students actually did tested the effectiveness of the MCE at level 1 of Figure 5. These were identified as missing gaps in the practice of laboratory work and alignment of activities to theory taught in class. It demanded and looked out for dexterity with the use of equipment and an understanding of the constructed tasks. The match between what the Researcher intended teacher-trainees to learn through the use of the MCE and what they actually learned demonstrated the effectiveness of the MCE tasks as indicated at level 2.The special qualities of the MCE which makes it versatile and easy to use and was chosen over and above the standard traditional laboratory equipment are outlined below.

**Background to the use of Micro Chemistry Equipment in schools and classrooms**

The adoption of microscale chemistry for the teaching of chemistry in Southern Africa and Asia is largely due to the immense efforts of Bradley, an English photochemist at the University of the Witwatersrand in South Africa, and of his collaborators (Ibanez, 2012). Microscale chemistry took off when the potential of microwell plates were recognised by scientists. They were and are still used a lot in the medical field. Enthusiasts developed a repertoire of simple microscale experiments using these wells in the medical and science research laboratories. Soon they caught on in the school laboratories and classrooms and as activities were easier and faster to perform on the micro scale level, they appealed to some liberated chemistry teachers. There was the added greater safety that they derived from the micro activities. In addition, the micro equipment could be used for both qualitative and quantitative chemistry practical activities and give almost as accurate results as the traditional macro glassware. This was deemed attractive to UNESCO and scientists (UNESCO, 2006) who had for many years advocated the development of low-cost equipment to poorer communities. The organisation therefore found it very laudable to encourage the use of micro equipment in undeveloped and developing communities. These communities often or always had no funds for traditional science equipment which had to be imported from the developed countries. The UNESCO (2006) project used introductory workshops in cooperation with teachers and curriculum developers often nominated by the Ministry of Education of chosen countries. The results were always overwhelming at the start. The projects however failed each time enthusiasts of the project retired (Bell & Bradley, 2012). They also failed in schools where teachers were ill-prepared and lacked experience with managing practical work. This is why it is important that teacher –trainees be trained in the design, uses, maintenance and benefits of low-cost micro chemistry equipment before they go out to teach. They must understand the robust nature of the MCE in particular, and the number as well as types of activities that they can conveniently use the MCE for to enhance learning. At the start of the UNESCO /MCE project, the ill-prepared teachers‟ lesson experiences were reported to be disappointing. They often misplaced items of equipment. In this way, their resources diminished and activities could no longer be performed. Chemicals were not replenished and the micro scale approach was abandoned. These efforts were followed by the Global Microscience Project by UNESCO to specifically introduce the concept into needy countries (Bell & Bradley, 2012).

Microchemistry can be practised anywhere. There is no need for a formal laboratory. They are best used in a regular classroom where the practical activity can be integrated or worked alongside other theoretical activities (Ibanez, 2012). The kits and chemicals are minute and so they can easily be transported between classrooms and the storage room with little difficulty. The waste which is generated is also not bothersome as it is small in quantity and will give no environmental disposal problem.

Activities involving the use of MCE are "interactive". Traditional laboratory experiences point students' attention to getting "good results" by following prescribed procedures. Students conduct observations and data collection in the laboratory, and go home to analyse results and draw conclusions. They tend to go through laboratory procedures passively without grasping related concepts. The exercises in the MCE approach aim at training students to become more careful observers and critical thinkers during the exercise. In many short, hands-on exercises, students test new ideas as they are being presented. They analyse results immediately, and are required to answer critical questions concerning an experiment before the experiment is over.

As experiments can be completed faster on the microscale than with traditional equipment, it is therefore possible for a teacher to plan a lesson around a practical activity. There is time for introduction of the aims of the lesson at the start of the lesson and for discussing results at the end so as to make a meaningful learning experience (Bell & Bradley, 2012). Again, to achieve this, the teacher needs to gain experiences and get support before such a project. It is in line with this that chemistry education teacher –trainees of the University of Education are being exposed to and trained in the use of microchemistry equipment experimentation. The MCE has been found to suffer minimal breakages. Consumables are less than 1 – 10% what the traditional experiment requires. Sample worksheets can easily be obtained at UNESCO and the Centre for Research and Development in Mathematics, Science and Technology Education (RADMASTE) sites online and adapted to suit one‟s national norms and curriculum (AJCE, 2012). In view of organising practical activities in Ghana to enhance the mastery of science concepts, the Micro Chemistry Equipment (MCE) which is robust and affordable was used in this study. This was done through an intervention in which regular chemistry laboratory practical activities were organised for chemistry major students. The MCE has been known as having singular qualities that facilitate their use in all types of schools -whether endowed or less endowed (Bell & Bradley, 2012). Thus, in Ghana, where majority of our schools are in rural and deprived communities, the use of micro chemistry equipment is a relevant option for the school system, since the MCE has been packaged as an appropriate and less expensive substitute for standard (but expensive) laboratory equipment. The use of the MCE approach is known to have facilitated hands-on practical activities in schools and contributed to science concept development (IUPAC, 2000).

This study exposed teacher-trainees to exciting laboratory practical activities that helped them to develop conceptual understanding of selected basic inorganic chemistry concepts. It is hoped that the trainees would use the skills they have acquired to teach chemistry effectively in our Ghanaian schools.

**Advantages and disadvantages of the MCE**

Micro scale chemistry as indicated earlier reduces the amounts of chemical substances used. By decreasing the quantities of these substances to the minimum level at which experiments can be effectively performed, chemical waste is reduced (Kelkar & Dhavale; 2000 Huang, 2007). MCE experiments have other additional advantages such as:

- Save time for preparation and cleaning
- Reduce waste at the source
- Encourage students to think about waste management
- More safety
- Lower costs for chemical substances and equipment
- Smaller storage area
- Reduced reliance on intensive ventilation systems
- Pleasant working atmosphere
- Shorter reaction time
- More time for evaluation and communication
- Suitable for early childhood education
- Versatile for both qualitative and quantitative chemical analysis

Altun, Demirdag, Feyzioglu, Ates, and Cobanoglu (2009) have added that MCE allows for repetition of activities at learners" own pace. In addition learners are able to access results of activities in shorter times relative to traditional macro experiments. They went on to report that, more importantly, learners are able to change variables wihout fear and receive immediate feedback, which is very encouraging for the facilitation of concepts. The substances and materials for MCE are in the range between 5 millilitre and 5 microlitre (1 mg). Most of the substances suggested for use are available in chemical and equipment supply shops in the developing countries, thus obtaining resources for activities at will and as often times as possible, poses no problem. Traditionally, experiments in chemistry are carried out on a macro scale level, employing quantities of chemicals on the order of 5-100 g, using glassware designed to contain between 25 and 500 $cm^3$ of liquids. It could even go up to 2000 $cm^3$ of liquids or chemical requirements. That means a lot of money would be required for the purchase of chemicals and equipment.

Mafumiko (2006) and Altrun et al. (2009) have asserted that the MCE is not entirely flawless. To begin teaching using MCE techniques in the laboratory, an institution must purchase micro scale equipment and textbooks. However, the costs can be recovered in a relatively short period due to savings realised on purchase and disposal costs of reduced quantities of chemicals. Again, experiments involving the use of strong acids such as undiluted HCl and $H_2SO_4$ of molar concentration greater than 10M as well as caustics like NaOH are reduced to the barest minimum. Despite these disadvantages, the enormous benefits of the MCE makes it a versatile laboratory kit for use (Bradley, 1999b) especially in disadvantaged and rural communities in Ghana to promote concept formation in science in general and chemistry in particular.

**Importance of practical work and content knowledge base for teachers**

Laboratory activities play a distinctive and central role in the chemistry curriculum. Many science educators have suggested some of the many benefits, including conceptual developments, which accrue from engaging students in laboratory activities (Hofstein & Lunetta, 2004). Observation and being on the teaching job for over twenty years has shown that lecturers are often bogged down with so much work that they do not make time to teach themselves nor learn to use innovative approaches in their teaching. It is important that we take the bull by the horn and teach ourselves and students of science newer ways of teaching chemistry practical work effectively in consonance with Ghana‟s new educational structure. This is because the new curriculum for science has about 50% of practical work and active learning while the remaining 50% is based on theoretical acquisition of content or subject matter and attitudes (CRDD, 2006).

In addition to a focus on subject matter content, (Britton & Anderson, 2010; Little, 2005) make the case that the content of professional development needs to be aligned with school goals and be robust enough to bring about the hoped-for changes in teaching. In order to be a robust chemistry teacher or trainee one will have to enhance their own understanding of concepts for transfer through concept-based activities (Kolb, Boyatzis, & Mainenelis, 2001). Weak content knowledge can sabotage one‟s sincerest attempts to improve teaching. Although this repetitive or constant practice of activity is almost in consonance with the behavioural theory of teaching, since it talks about a repertoire of strategies, practical work is only being used as a means out of many others to achieve the aim of concept learning. How Ghanaian teachers have been managing their own development with conceptual teaching and learning of science (chemistry) by their students in their schools will be discussed in the next session.

**The teaching and learning of science (chemistry) in Ghana**

Ghana has had a few policies on science education in the past four decades. Before the early 1980s, science was taught as nature study in the primary and middle schools, where pupils basically learned about hygiene and things found in their natural environment. Later, science was taught as environmental studies in the lower basic school. With the introduction of the junior high school system, science was taught as general science (Ghana Government Portal, 2011). The science curriculum was a modern replacement of what used to be called "nature study." This "general science" was a generalist, survey course, which exposed the child to the universe. At this level, students got basic exposure to scientific ideas, and learned about the history of science. They also learned basic scientific vocabulary at this level.

In the last decade, the science curriculum has been called integrated science. Regardless the change of names the same issues and topics have been taught (Adegoke, 2003). The Ghanaian science curriculum follows the "spiral approach". It treats the same themes at different times and in greater depths within ascending educational level. The mode of teaching has also been about the same – basically the theoretical mode (Antwi, 2013). The curriculum at the senior high school level comprises integrated science. At this level, the students are exposed to the rudiments of physics, chemistry, and biology as a general course. For those who qualify to read the pure science option in the senior high schools, their curriculum includes the individual disciplines of physics, chemistry, biology, and additional mathematics. The curriculum shows that students are expected to carry out practical activities so as to be able to understand concepts in the various science disciplines. A situational assessment in selected schools by the Researcher indicated that little laboratory work was practised. At best, final year students were quickly taken through the rudiments of practical activities which are required by the final national examining body so that they can pass their practical work successfully in the school‟s final and national examinations.

The teaching of chemistry in particular, and science in general in Africa, has been dominated by theoretical lectures (Antwi, 2013) which limit students‟ understanding of various chemical concepts and principles. This theoretical approach, coupled with the abstract nature of the subject interferes with students‟ creativity and understanding capacities. In addition to the abstract nature of chemistry or science in general, Africans have a culture which depicts elders as custodians of knowledge and so make learners unassertive in the learning process. There is also the added missionary influence of obedience and submissiveness among Africans. These create a complex situation which does not allow the African student of science to be exertive and exploratory, naturally. Besides, most African countries, Ghana inclusive, do not have the financial capacity to equip institutions with the needed traditional science equipment, materials and chemicals to really teach interactive chemistry as a practical enterprise. In the teaching university and colleges of education in Ghana, observations from field studies indicate that the frequency of science practical activities are far less than stipulated by their respective curricula. Time for laboratory work is often set aside for theory work. These mishaps could be attributed to the lack of resources, time, shortage of teachers and technicians, lack of expertise and confidence among teachers due to academic incompetency and a few others.

One possible way to deal with this paradox of lack, and yet the need to equip students with chemical concepts and ideas, will be to build the capacity of chemistry teacher trainees in the design and use of low cost or simple-to-handle science equipment. The introduction of low-cost, yet versatile equipment which can be used to enhance concept formation could be a solution in the face of lack of time, expertise, resources and equipment. Though attempts have been made by the United Nations Educational Scientific and Cultural Organization (UNESCO, 2006) for teachers all over the world to develop low-cost educational materials from local resources, the project has been fraught with many problems. Another drawback to the UNESCO (2006) proposition was the fact which still remains, that teachers have little time to constantly produce these materials themselves (Yitbarek, 2012).

Regardless the outlined problems that Ghana and Africa as a whole is facing, the benefits of practical activities in the context of science teaching and learning cannot be overlooked. Eijkelhof (2002), and Millar (2004) have given many good reasons for using practical work in school science education. They have said that practical work provides an opportunity for students to relate to abstract lectures as it helps them develop and acquire scientific skills. Practical activities stimulate students‟ curiosity and imagination and offer them the opportunity to interact with each other as well as with their teachers on more personal and informal ways. Again, they stimulate the creativity of teachers and learners to use their skills for the improvement of chemistry lessons. In addition, they provide teachers with valuable opportunity for direct and individual teaching as they move round to supervise students‟ activities. Designed activities also help students to be acquainted with subject-oriented language as they are able to speak freely in the context of their science working situations.

**Some modern learning theories that support the use of MCE**

In this section four learning theories of learning have been discussed. They are the generative learning model, cognitive theory, constructivist theory and experiential learning theory. Learning is an active process which occurs when students have a chance to construct understanding through empirical investigation and social interaction with others to gain cognition (Little, 2005). The theoretical underpinnings of learner-centred models reflect a constructivist tradition that focuses on individual activity and the importance of exploring physical phenomena as a starting point for personal construction of meaning (Duit, 2011). Sociocultural cognitive models portray learning as a process of cultural apprenticeship in which knowledge is constructed as a result of social interaction (Vygotsky, 1978; Holton & Clarke,2006; Lemke, 2007). For social cognitivists, learning science involves learning the ideas and practices of the scientific community and making them meaningful at an individual level. This assertion, though laudable, is contrary to the constructivists‟ view of allowing free rein in learning environments for individual construction of knowledge (Martin & Loomis, 2013). A central tenet in both assertions is that students cannot achieve high levels of performance without access to an array of learning materials that offer hands-on and minds-on experiences. Active learning involves interaction with others. This is supported by findings from a strand of research on social constructivism (Scott, Asoko, Driver, & Emberton, 2012). Active learning is necessary for understanding, acquiring and retention of knowledge (Keyser, 2000). During active learning, students actively work with their prior knowledge, as they present them as output. In this way, knowledge can be integrated into existing schema, or new ones constructed on particular topics. Whether an activity is effective in enhancing or generating new knowledge and schema acquisition by learners depends on what they do in exercises and the way knowledge is built (Diederen, Gruppen, Hartog, Moerland, & Voragen, 2003). The similarity between the two schools of thought (cognitivist and constructivists), with regard to concept formation, is the student directed programme. Such a directed programme could be in the form of special MCE curriculum materials for students.

According to Tsai and Huang (2002), knowledge is not transmitted directly from one person to another but actively constructed by the learner. This presupposes that an activity of a sort must be performed for a concept to be constructed. Concept formation in science thus, has to be active and generative for students to develop sound and lasting understanding in their minds. The term “active learning” was put forth by Ritchie and Volkl (2000) to describe an ideal way of interactive teaching. According to Ritchie and Volkl (2000), a „generative" approach combines many different strategies which create a very enabling environment to make students of all types active and responsible for constructing meaning from activities. The generative environment helps them to build relationships across subject matter contents and between the subject matter and their existing knowledge. The MCE activities are designed to follow the „generative" approach.

The essence of the generative learning model is that the brain is not a passive consumer of information but actively constructs its own interpretations of information and draws inferences from them. Generative activities induce the learner to construct relevant representations that they would not compose spontaneously. In this case, there is a deliberate attempt to get students to think of other linkages other than those they normally would have thought of. Thus, learning is expanded by individuals. Learning is able to take place when links are generated between the contents of short-term memory and other knowledge base or long-term memory. An individual"s memory will improve dramatically if he provides some of the to-be –remembered information himself, especially through *doing*. This implies that, learners must be made to do activities of theories studied so as to be able to construct their own knowledge on that theory. In the constructivists view (Martin & Loomis, 2013) knowledge is a dynamic conceptual means of making sense of experience practically rather than a passive representation of an extant world. Each individual must construct their own knowledge if they are to be truly useful and memorable to them.

According to Kolb, Boyatzis and Mainernelis (2001), experiential theorists, though, do not emphasise on cognitive development only as the cognitivists do, nor on behavioural theories that deny any role for subjective experience in the learning process. Their ultimate and implicit aims are that cognition and sound concept formation are gained through personal experience by the end of a learning period. The experiential learning theory defines learning as „the process whereby knowledge is created through the transformation of experience. Not only does it provide a holistic model of a learning process but a multilinear model of adult development. According to Akella (2010), knowledge gain and concept formation resuls from the combination of grasping and transforming experiences. The theory presents a cyclical model of learning, consisting of four stages as shown in Figure 6. One may begin at any stage, but must follow each other in the sequence: concrete experience (or "Do"), reflective observation (or "Observe"), abstract conceptualization (or "Think"), active experimentation (or "Plan").

The use of the MCE approach would also provide opportunity for chemistry teacher-trainees to think and plan MCE activities, make observations and reflect on their outcomes in order to make informed and logical conclusions from practical activities. Kolb‟s experiential cycle was followed during MCE practical activities as can be observed from the trainees‟ worksheet in Appendix G (Anderson & Krathwohl, 2001).

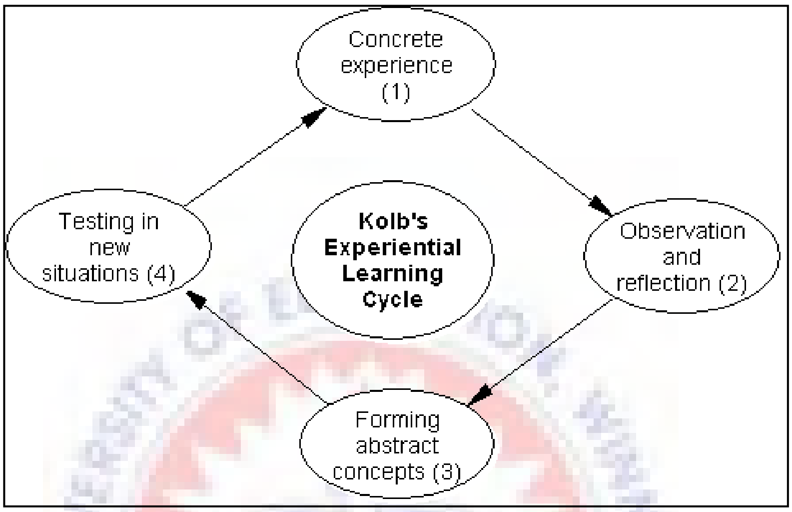


**Figure 6: Kolb's Experiential Learning Cycle**

Experiential learning emphasises the central role that experience plays in the learning process. According to one of the theory‟s four-stage learning cycle, concrete experiences are the basis for observations and reflections. These reflections are assimilated and metamorphosised into abstract concepts from which new implications for other actions can be drawn. These implications can be actively tested and serve as guides for creating new experiences. In the MCE practical activities (Appendices F & G) trainees carried out scaffolded activities, made their own observations and reflected on their outcomes. With their newly formed ideas they carried out follow up activities which required the use of knowledge gained or their understanding of their previous MCE activities in new circumstances. Positive applications in new circumstances meant that new conceptions have been gained. Kolb‟s experiential learning theory is a holistic perspective that combines experience, perception, cognition, and behaviour. The experiential theory works in line with the MCE approach which affords trainees the opportunity to experiment, try out their own ideas, engage in positive cognitive conflicts and re-orient their perceptions with an „ahaa" or „I now get it" expression. Contrary to the fact that constant or repetitive practice will bring about conception, too many new ideas and much work assigned to students at a time could create chaos or „overload" in the working memories of learners" minds. The „overload" like noise, will not yield any meaningful learning but may rather lead to the development of alternative conceptions.

The MCE approach also encourages collaborative learning since students work in pairs or groups. Collaborative learning is a situation in which two or more people learn or attempt to learn something together. Unlike individual learning, people engaged in collaborative learning capitalize on one another"s resources and skills (asking one another for information, evaluating one another"s ideas and monitoring one another"s work). More specifically, collaborative learning is based on the model that knowledge can be created within a population where members actively interact by sharing experiences and take on asymmetry roles (Chiu, 2008). Put differently, collaborative learning refers to methodologies and environments in which learners engage in a common task where each individual depends on and is accountable to another (Chiu, 2000).

To provide enhanced opportunities for interactive learning, students are generally encouraged to work in groups. According to Ding and Harskamp (2011), learning is a structured, systematic instructional strategy in which small groups of students work together toward a common goal. Thus, collaborative learning is commonly illustrated when groups of students work together to search for understanding, meaning, or solutions. Collaborative learning is heavily rooted in Vygotsky"s views that there exists an inherent social nature of learning which is shown through his theory of zone of proximal development (Chen & Chiu, 2008). Often, collaborative learning is used as an umbrella term for a variety of approaches in education that involve joint intellectual effort by students or students and teachers. Its models are based on the premise that learning is best achieved interactively rather than through a one-way transmission process, even though each individual mind processes information differently. This information processing capacity of the brain will however not be discussed here.

It is envisaged by the Researcher that collaboration during practical activities will take a lot of cognitive load off each individual through collaborative discussions. The term cognitive load (CL) is used in cognitive psychology to illustrate the load related to the executive control of working memory. The working memory refers to a limited capacity system allowing the temporary storage and manipulation of information necessary for complex tasks such as comprehension, learning and reasoning (Baddeley, 2000). Cognitive load refers to the total amount of mental activity imposed on working memory at any instance. Theories contend that during complex learning activities the amount of information and interactions that must be processed simultaneously can either under-load, or overload the finite amount of working memory one possesses. In each case, all elements must be processed before meaningful learning can continue. The Cognitive Load Theory (CLT) (Kirschner, 2002), assumed a limited capacity of working memory and a very large long term memory that holds schemata. CL may be affected by the inherent nature of the material, the manner in which the material is presented and the activities required from learners (Kirschner, 2002). Constructive and active activities tend to minimise cognitive load on students.

According to Paas, Renkl and Sweller (2003), activities that are irrelevant to construction of schemata should be minimised as they tend to put a strain on the abilities of students to comprehend and form their own true concepts. For a course such as inorganic chemistry, in which many dissimilar facts are related, it is important to ensure adequate levels of CL are imposed. Information should be properly sequenced and presented at just the appropriate time. Another aspect of cognitive load theory involves understanding how many discrete units of information can be retained in short term memory. Since people process information differently but all based on chunking into repetitive bits, the MCE curriculum materials have been designed in this way to allow for ease of processing by students. It is hoped that students would find the provision of the MCE kit and its accompanying worksheets an enabling environment for inquiry learning.

This research will adopt the experiential and constructivist theories, particularly, cognitive constructivism to bridge the identified gap in the teaching–learning process towards concept development in chemistry teaching and learning at UEW. This is basically because knowledge would be expected to be constructed by learners, based on existing structures. They would be allowed to set their own goals and learn how to motivate themselves to learn as teacher trainees so that they can impart that technique to their students when they go out to teach. The desired kind of learning here would be one that would enable trainees to remember adeptly, understand concepts, apply concepts, analyse concepts critically, evaluate and have the ability to create or design new products in challenging situations. Learning would be facilitated by providing an environment that promotes discovery and assimilation through trainees‟ experience with equipment and chemical resources. The cognitive load at each point in time of their study would be carefully assessed to ensure that the load is not over or under the trainees" capabilities. It has been found through research that the amount of information to be processed affects how much a student can learn at any point in time – whether they can accommodate the information or not.

From the discussions so far, it has become evident that management of practical work in schools, especially in developing countries in Sub-Saharan Africa has been a problem. The supply of equipment in the midst of scare resources has not been of much help sometimes as a result of the none-use of equipment due to its sophisticated nature and replacement issues. Overload of the science syllabus with examination - driven demands have also led to teacher-centred lessons (PRACTICAL, Final Project Report, 2010). These have resulted in the formation of alternative frameworks and concepts by students. Some alternative conceptions are tenacious and resistant to extinction by conventional teaching strategies as Taber (2002) contended. It is therefore important that teachers develop novel methods of teaching and conducting practical lessons. UNESCO reports have indicated that often, teachers did not have the expertise and confidence in using equipment and setting up practical work for students. Thus, practical lessons were converted into theory lessons. In some well-endowed schools in Nigeria, Egypt, and other parts of Africa, equipment and consumables were reserved for use during critical periods such as during national examinations (Abimbola, 2001). The importance of practical work to students has also been discussed. A search through literature proved beyond doubt that practical work provides opportunities for students to go beyond words and abstract symbols and elucidate important basic points of theory or concepts (Abdullah, Mohamed, & Hj Ismail, 2009; Abrahams & Millar, 2008; Horton, 2007). Chemistry practical activities stimulate students" imagination and curiosity. Again, it provides opportunities for students to interact with each other and with their teachers. Practical work should thus be an integral part of teaching and learning. To solve the emerging problem of large class size issues and the performance of practical work, the use of MCE and experimentation was seen as a promising solution. It was also seen as a tool for science concept development. Studies by Bradley (2000), Singh, McGowan, Szafran & Pike (2000) as well as Gebrekidan, Lykknes and Kvittingen (2014), have indicated that high school students showed a positive attitude towards the use of MCE. Other findings such as Mafumiko"s study in Tanzania (2006; 2008) included safety, enhancement of student laboratory skills, more focus on understanding of concepts rather than the manipulation of equipment, gain in cognition and more time allowed for questions and discussion.

**Empirical evidence of the use of MCEs in chemistry education**

Micro chemistry equipment was first designed in the 1990s in South Africa by the Centre for Research and Development in Mathematics, Science and Technology Education (RADMASTE) under the auspices of John Bradley (Motswiri, 2004). Bradley took an interest in bringing laboratory experiences to schools in South Africa during the apartheid period to black students. He therefore developed the micro or miniature chemistry kits. Micro scale chemistry is an approach to teaching chemistry by working with small quantities of chemical substances (Bell & Bradley, 2012). It is a way to reduce the amounts of expensive chemicals with expensive equipment needed in experimentation. MCE has been used extensively in both developing and developed countries but not so much in Ghana. Evidences from literature shows that MCEs have been used in the United States of America, Russia, United Kingdom, Germany, The Netherlands, Thailand, Malaysia, and Turkey. In a journal on chemistry education in Africa, Ibanez (2012) from Mexico, Bell and Bradley (2012) from South Africa, Yitbarek (2012 ) from Ethiopia, Engida (2012) also in Ethiopia and the science section of UNESCO in Paris all trace the history and use of MCE in both developed and developing countries. In Africa, MCE has widely been used in South Africa, Cameroon, Angola, Ethiopia and Namibia. Experiences from many developing countries demonstrate that the quality of science education is often unsatisfactory, with respect to acquisition and use of equipment (Sileshi, 2012). Often, science educators show a strong resistance to low-cost equipment because they assume that it leads to second rate science teaching and creates alternative conceptions as a result of poorly calibrated equipment and subsequent incorrect outcomes. In contrast to the above assertion, Sileshi (2012) was of the view that simpler equipment has distinct educational advantages. The Gambia and Palestinian Authority have held workshops to adapt the micro kits to their respective national education curricula. UNESCO has obtained funds for MCE projects in Cameroon, Mozambique and Tanzania. Gambia"s president has requested the supply of and introduction of MCE into senior high schools which lack funds to equip its science laboratories. Countries such as Cape Verde, Rwanda, Albania, Tanzania, Uruguay and Vietnam have even requested help from international organisations for supply of MCE for teacher training (UNESCO, 2011).

Bell and Bradley (2012) did a current assessment of the microchemistry equipment situation in Africa over a span of 30 years. They found out that teachers adopted the MCE because they were easier, cheaper and safer to work with. Their use required small amounts of chemicals. UNESCO, on realising the potential of the MCE, championed its cause so as to reach out to poorer communities through introduction workshops in conjunction with their education sectors. Bell and Bradley also found out that most of these efforts wilted away because of poor policies and lack of government support. In some cases, the supplied kits and chemicals were not integrated into chemistry teaching. Despite all these, Bell and Bradley were optimistic that the use of the MCE would become popular with the dwindling of global finances.

Mafumiko (2008), reported on views of participants in a summative phase of a study on the use of MCE as a catalyst in enhancing concept development among high school students and teachers in Tanzania. He used MCE exemplary curriculum materials.to support teachers with the implementation of practical work in A-level chemistry classrooms. All activities were done in a regular classroom where practical activities were integrated with „theoretical‟ activities. His evaluation involved field testing of the materials to investigate the effectiveness of the MCE approach when compared to „traditional‟ teaching approaches on the topic- solubility and precipitation. Teachers reported on their positive professional development and experiences. Their students developed better scientific reasoning skills and they did better reflection on the topic studied. In conclusion, Mafumiko found that the MCE approach was feasible for use in A-level chemistry classes and effective in providing positive learning experiences for students.

A similar study carried out by Kombo (2006) in a teacher training college in Mozambique revealed that equipping distant education teacher-trainees with the MCE-approach teaching skills was a positive venture. The study was undertaken to introduce the micro science kit approach as a means to perform practical work in secondary education without the need for well-equipped laboratories and to provide opportunities for students to engage in a process of active learning. He concluded that micro kits had the potential to improve teaching and learning practices in science classes in Mozambique and in particular, within the Centre for Distance Education programme. Kombo added that the micro science kits provided positive learning experiences for the distance teacher trainees and helped them to develop better reasoning skills by providing them more opportunities for practical work.

Under a new UNESCO-sponsored project, MCE school packs are to be sent to 32 countries (unnamed) across the world before the year 2015 (UNESCO, 2011). This illustrates the power of the MCE concept to enhance the teaching of science and enable a more inclusive and richer science education. This new UNESCO outreach will increase interest in science and growth of public understanding of science and in the long run enhance scientific and technological development and maintenance.

**Evaluation studies**

Evaluation is a widespread activity in the education and social science circles. In the 1950s and 1960s the term evaluation was defined as the systematic assessment of the worth or merit of some object (Adelma, 2004). Adelma went on to add that evaluation in educational studies involves the making of judgements about the effectiveness of educational intentions, processes and their outcomes. Trochim (2002) in the United States defines evaluation as the systematic acquisition and assessment of information to provide useful feedback about some object. Trochims"s definition extends the scope of evaluation as compared to that of Adelma (2004). Evaluation research could be likened to project evaluation (Ofori & Dampson, 2011). Evaluation makes comparison among products and services with a view to making comparisons. Evaluation of an innovation or an activity, a curriculum or organisational change, raises contentious issues such as what has to be known and why it has to be known. Evaluative studies finds out and answers questions such as *whether an innovation will require more or less finance, cause promotion or redundancy, cause a change in student learning* …? In this research, the evaluation of teaching quality and concept formation will not be considered. The emphasis will be on evaluation of the impact of MCE on concept development among teacher-trainees.

In evaluative studies, the evaluator"s role is to be objective in collecting data scientifically, use feedback obtained from participants, define the nature and methodology of the programme, investigate the outcomes and judge whether the project has been worth the try. Determinants such as change in knowledge, attitudes, beliefs, skills or values are set as standards so that a measure of change in the determinants could be used to evaluate an educational progress (Silver, 2006).

*Some probable evaluation questions could be:*

*How much did participants' knowledge of chemical bonding change due to a programme (MCE)?*

*Are chemistry teacher-trainees likely to design concept-based practical activities because of the MCE innovation?*

The most common way to answer these questions would be through the use of pre and post-tests or surveys as they provide a good way to compare participants" efforts, skills, performance and other assessment variables before and after an intervention. Correlation of data are also useful means of finding the relations between experimental and assessment variables which could have relational effects. Diagnostic tests, in particular, are proving to be the good diagnostic tools for such evaluative purposes as proposed by Treagust (2006). The processes of research evaluation are to engage stakeholders (teacher-trainees), focus (describe and define purpose and select indicators or determinants), collect data on a sample through a selected method, analyse and interpret data and then use or share the findings. The evaluation (analysing what was learned) could be for a short period or for a number of years. The main goal of an evaluation report could therefore be said to be to inform or influence decision makers.

**Diagnostic concept tests**

Many different types of tests have been used to assess students‟ summative learning. Qualitative approaches such as open-ended responses (Nyachwaya, et al., 2011), and clinical interviews (Costu, 2008) though time consuming, have widely been used to investigate students‟ thinking and conceptual understanding. Multiple choice tests are however less tedious and convenient to use in standardised and classroom tests. (Examinations Institute, 2011), besides they cover content as broadly as possible to reflect students‟ cumulative knowledge. Multiple choice tests therefore provide some informed status of a students‟ gain or otherwise in content knowledge at the end of a topic or course. Regardless the benefits discussed, the interpretation of each item in summative tests cannot specifically provide information about the alternative concepts students have about chemistry concepts. Diagnostic concept tests are designed tiered multiple tests which have a trait for elucidating students‟ own ideas about science concepts. Some diagnostic tools are simple multiple choice questions, concept tests, interviews and dyads. Chemistry-based diagnostic tests have been developed and used to measure student alternative conceptions (Voska & Heikkinen, 2000; Tsai & Chou, 2002). According to Treagust (2006), diagnostic tools have the advantage of helping educators and researchers to gain insights into conceptions held by students. The first tier of each item is a multiple-choice question that relates to a problem statement or content question. The second tier of each item is composed of a set of explanations or reasoning responses for the answers from the first tier. The second tier or reasoning part can provide information about which alternative conceptions students have about a chemistry concept under study. Treagust (2006), found the use of justifications when answering multiple-choice test items to be a sensitive and effective way of assessing meaningful learning among students and addresses the limitations in traditional multiple choice tests to some extent. The formats of most diagnostic assessments vary depending on the developers‟ goals, but most are multiple-choice so that they can be quickly administered and reliably scored. Treagust suggested that designers should use prior research, concept maps and propositional knowledge to build two-tier items. McClary & Bretz (2012), agrees with Treagust that items on two-tier instruments offer an opportunity to gain insight into students‟ mental models more efficiently than think-aloud interviews and other assessment tools. Two-tiered diagnostic instruments can tell educators more about students‟ conceptions as related to a given topic. Diagnostic assessments covering a range of topics in chemistry have been reported, including particulate nature of matter (Nyachwaya, et al., 2011) kinetic particle theory (Treagust, et al., 2012) acids and bases (Rahayu, Chandrasegaran, Treagust, Kita, & Ibnu, 2011) and chemical equilibrium (Voska & Heikkinen, 2000). Diagnostic assessment has also been used to assess students‟ attitudes about chemistry (Bauer, 2005; Brandreit, Xu, Bretz, & Lewis, 2011).

Other methods which have been used to diagnose students‟ conceptual understanding of chemical bonding include concept mapping (Haider & Al Naqabi, 2008), and multiple-choice diagnostic instruments by Tan, Goh, Chia and Treagust (2002). Observation, explanations, concept phase diagrams, guesses, diagrams, question forming, two-tier test are all used to determine alternative concepts. Alternative concepts have to be identified so that measures can be taken to help students to acquire more scientifically acceptable concepts. Tan, Goh, Chia and Treagust (2002), Chou and Chiu (2004), Wang (2004), Treagust (2006), Chandrasegaran, Treagust and Macerino (2007), Taber and Tan (2007), Tan et al., (2008), have all tried to use diagnostic tests to determine students‟ ACs in various chemistry topics. This study will use diagnostic test to identify possible teacher trainees‟ alternative concepts in periodic properties and acids and bases in UEW as the formation and transfer of these alternative concepts have been affirmed to be global. A common approach in two-tiered test to discover alternative concepts and build scientific ones is to see if at least 10% of a given sample has difficulty understanding given scientific concepts (Tan, Goh, Chia & Treagust, 2002). It will not be appropriate to use a percentage higher than 10 because most wrong concepts of learners would be overlooked.

**Correlation studies**

A correlational study determines whether or not two variables are correlated. This means to study whether an increase or decrease in one variable corresponds to an increase or decrease in the other variable. Correlation research is looking for variables that seem to interact with each other, so that when you can see one changing, you have an idea of how the other would change. It explores the cause and effect (causal study) linkages among groups and elements. A correlation coefficient is usually used during a correlational study. It varies between +1 and -1. A value close to +1 indicates a strong positive correlation while a value close to -1 indicates strong negative correlation. A value near zero shows that the variables are uncorrelated. In this study, trainees" performances in assigned tests were correlated to identify linkages.

**Theoretical framework**

In action research, which is akin to developmental research, the conceptual and theoretical framework for the study may be found in literature, from actual practice environments as well as from traditional research literature directed towards theory construction. A theoretical framework is a structure of concepts which exists in the literature and come together to form a ready-made map for the study. It is a collection of interrelated concepts which guide a research, determines what things to measure, and what statistical relationships to look for. Developmental research is the systematic study of designing, developing and evaluating instructional programmes, processes and products that must meet the criteria of internal consistency and effectiveness (Reeves, Herrington, & Oliver, 2004; Gall, 2007). Developmental research often occurs in natural work environments such as the classroom. It seeks to create knowledge grounded in data systematically derived from practice. In addition, it is a way to establish new procedures, techniques and tools based upon a methodical analysis of specific cases. As such, developmental research can have a function of either creating generalizable conclusions or statements of law, or producing context-specific knowledge that serves a problem solving function. The purpose of developmental research is to assess changes over an extended period of time. A developmental research framework is one that, among other key characteristics, "involves intensive collaboration among researchers and practitioners" and "maintains a commitment to theory construction and explanation while solving real-world problems" (Reeves, Herrington, & Oliver, 2004). This approach is also known as design or action research (McNiff & Whitehead, 2002). Action research could be developmental in nature. Developmental studies are often structured in phases as has been described in the next chapter. The framework discussed above was used in developing a model for" the naïve ideas and concept formation among teacher-trainees. The constructivist theory as well as natural classroom experiences (Kolb & Kolb, 2005) formed the basis for the framework of this study. Part of the development of a theoretical framework for this study also emanated from the practical activities of Level 100 inorganic pre-service teachers and the idea of constructivism based on the works of Ausubel, Piaget and Vygotsky.

Although constructivism is not a framework, the theoretical stance may be said to be constructivism. Constructivism is based on the assumption that students come into class with prior knowledge on events and personal interactions with their natural environments. It is upon this prior knowledge that new knowledge is structured. Thus, though concept formation is based on one‟s ability to define similarities and differences to build new ideas it is dependent on existing knowledge, observation, experiments and predictions as schematically presented in Figure 7.

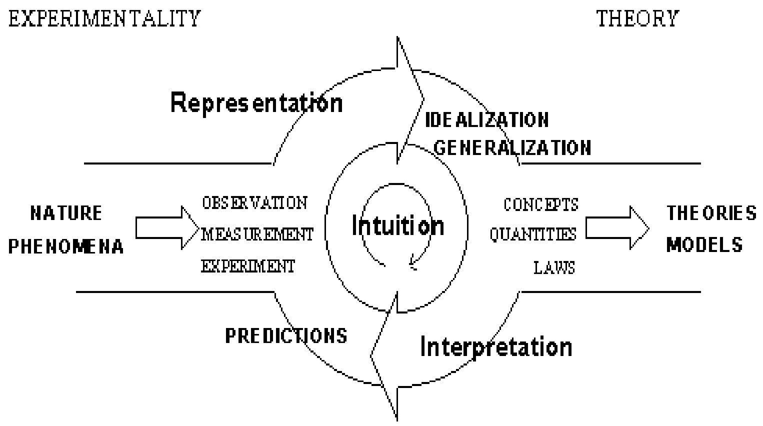


**Figure 7: Experimentalism Theory Schema**

There has been controversy over whether to refer to student conceptions that are not in accord with those held by scientists as „preconceptions‟, „student theories‟ or „misconceptions‟. „Misconceptions‟ seems excessively judgmental in view of the tentative nature of science and the fact that many of these conceptions have been useful to the students in the past. „Preconceptions‟ glosses over the fact that many of these conceptions arise during the course of instruction. Use of the expression, „student alternative conceptions‟, was finally agreed upon.

Wenning (2008) asserted that „student theories‟ can interfere with the common scientific meaning of concepts and theories being taught and result in misconceptions or alternative frameworks. In unfamiliar new problems and in everyday life the original „student theories‟ take precedence over the „scientist theories‟ taught. Sometimes, these conflict with the intended scientific theory to be learned and create misconcepts or alterative concepts. Concepts however, are usually learned by abstracting the basic ideas and constructing a mental prototype rather than through a formal definition (Gelman, 2009). Science concepts are never lonesome. They receive meaning through their links with other concepts. For example, in chemistry, amount of substance- n- (measured in mole) is linked with mass, (m), molar mass, (M), and Avogadro‟s constant (L). Thus, students‟ alternative frameworks are important and have to be discovered and used as springboards to correct discovered alternative concepts.

The basis of this work was to ensure that trainees used practical activities and other representations where necessary to understand chemical concepts more effectively. It has been explained that students tend to develop their own understanding of scientific facts through their interaction with their environment. If these alternative concepts are deliberately identified and corrected better conceptual analysis, retention and application will occur. A diagrammatic representation of how concepts are generally developed how alternative concepts come about and how they could be corrected is shown in Figure 8.

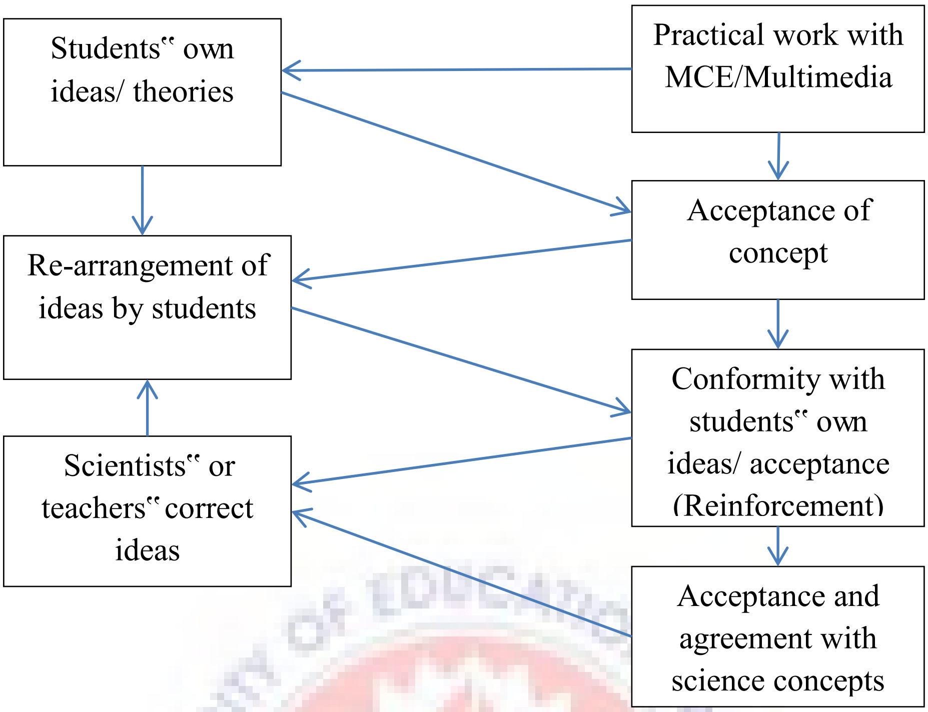


**Figure 8: A Schematic Diagram of the Formation and Correction of Alternative Concepts**

Figure 8, outlines some of the real processes that occur before students are able to do away with wrong or naïve concepts and re-construct correct scientific concepts in their place. During such a process, work is designed to exercise intellectual skills involved in generating and validating knowledge experimentally. The key to developing process skills is through student decisions (Hanson & Acquah, 2014). Students must be given opportunity to make decisions regarding what will be investigated and how to do it in order to build concepts. It is important to look for phenomena where particular dependent variables can be influenced by many independent ones and then have teacher-trainees investigate which variables can influence this dependent variable and the nature of this influence. Questions could also be asked concerning the weaknesses of experiments done and the methods employed. Processes employed in this current study were validated to ensure they were not merely copies of text book investigations which could allow trainees to copy from text books but on the other hand made their own decisions.

To help with increasing cognition, concept designs are formulated to result in such desired outcomes. They are carefully designed sequences of activities which systematically build up concepts and overcome misconceptions. Such a design allows for free communication between students as well as between students and teachers. It also encourages decision making. A diagrammatic representation on how to assess students‟ alternative conceptions, and put in interventions, to find out if conception has been gained through a process design is illustrated in Figure 9. This is a simplified representation of how concepts are formed with the use of micro chemistry equipment.

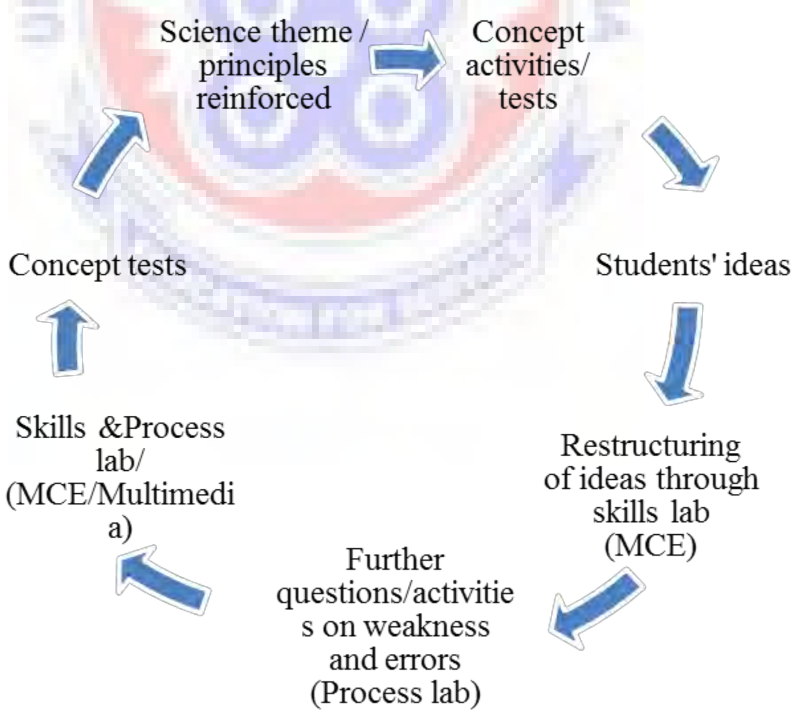


**Figure 9: A Schematic Diagram of the Process for the Formation, Identification, and Correction of Alternative Concepts**

Figure 9, unlike Figure 8, shows how alternative concepts are discovered, corrected and accepted concepts formed with the aid of diagnostic concept tests and the MCE approach.

**Summary of Chapter Two**

This chapter has reviewed literature related to the current study. It discussed the state of the nation‟s efforts at improving on education in general and science in particular. Reviewed literature focused on the current situation of lack of laboratories and equipment in the country and how micro chemistry equipment could be used to alleviate the situation. From context analysis, constraints to the understanding of chemistry theories through the implementation of practical work, as well as the lack of resources for practical activities, were identified. The importance of the role of diagnostic concept tests in identifying students‟ misconceptions and how the micro chemistry equipment could be used to help students to build correct chemical concepts from first principle were discussed. Theories on concept development were also reviewed with respect to interactive learning, such as the use of MCE-based practical activities. It assessed the importance of adopting design guidelines which would minimize students‟ workload and put less pressure on their memories (Gooding & Metz, 2011). The various types of alternative concepts and how they develop have also been presented. The best possible ways to minimize their occurrences were identified. There was a discussion on the importance of microchemistry in concept knowledge development as well as the role of accompanying curriculum materials in facilitating this concept development. A review of empirical evidence of the use of MCE in parts of the world revealed a gap in the contextual use of MCE, especially in the study of inorganic chemistry to bring about gains in conceptual cognition which this present study will address. The context analysis and literature review have provided adequate background information for design guidelines for the proposed conceptual change in the next chapter. It was however evident that a few shortfalls have to be filled, as virtually no information was found at the time of this study on the adoption and use of MCE for improvement of curriculum, concept development, the acquisition of learning skills and the improvement of students" attitudes towards learning through the use of the MCE. The next chapter discusses in detail, the method used in gathering data for the study to achieve a couple of the identified gaps.

# CHAPTER THREE

## RESEARCH METHODOLOGY

### Overview

This chapter discusses the methodology used in gathering data for this study. The details of the research design, the population, sample and stages or phases of the research are presented. An action research was used for data collection through eight organised chemistry lessons. Further, diagnostic concept tests, questionnaires, notes on classroom discourse and teacher"s log book, were also used to collect data. In the analyses of data, each instrument was separately examined for their contributions to the research questions. Finally, ethical issues concerning respondents" safety and confidentiality of their responses are discussed.

### Research Design

The design for this study was action research. In action research study, a cyclic nature of research is followed. Again, in this design, an exploratory stance is adopted, followed by the understanding of a problem and plans made for an intervention strategy (Gall, 2007). Action research follows a developmental cyclic process which allows for modifications. In action research, an exploratory stance is adopted through baseline studies of an identified problem. Interventions are planned and administered to rectify the identified problem. These initial interventions may or may not be answers to the problem and so new strategies will have to be adopted. The new interventional strategies are carried out and the cyclic process repeats until a sufficient understanding of the problem is achieved. Gall adds that, unlike the exploratory design, action research allows for the research process to continue over and again in a cyclic pattern. Observation is one of the main instruments used in action research. The only snag here is that action research is hard to write up because it often does not effectively lend itself to reporting in a standard format (Reason & Bradbury, 2001). The Researcher chose the action research design because of its many benefits to her and the participants in the research, as has been discussed above, regardless the difficulties with reporting all of one‟s findings.

Action research can be a powerfully liberating form of professional enquiry because it means that practitioners themselves investigate their practices as they find ways to live more fully in the direction of their educational values (McNiff & Whitehead, 2002). Further, action research helps a researcher to understand better what they are doing, why they have to do it, and use the knowledge acquired to improve an existing situation after their research (McNiff & Whitehead, 2010). The research design was an exploratory, developmental work without a control group. Developmental or action research is a systematic activity comprising both basic and applied research which aims at discovering solutions to identified problems or creates new knowledge in one‟s classroom or place of work (Reason & Bradbury, 2001; Gall, 2007). Action research does not test theories as some designs allow. It rather has direct and obvious relevance to practice and has no hidden controls or pre-emption of direction by the researcher. There could be no control group as this was a whole class study and a control group would have missed out on the new teaching technique, as well as the knowledge that was to be gained from the practical activities involving the use of micro chemistry equipment. All the teacher-trainees in this study were required to develop certain manipulative and process skills with the use of the Micro Chemistry Equipment (MCE). Thus, the study sought to evaluate the impact of the MCE approach on the selected pre-service chemistry teachers‟ cognition and skills in the use of micro chemistry equipment.

This research was designed to evaluate the effect of Micro Chemistry Equipment (MCE) based experiments on concept development of UEW chemistry teacher-trainees. The aim was to provide opportunities for these trainees to develop skills in the use of simple, low-cost, easy- to -obtain chemistry equipment. It was hoped that it would enhance teacher-trainee (student) as well as student-student classroom interactions, and further help the trainees to gain better understanding of chemistry concepts. The situational analysis as well as reviewed literature provided background information out of which guidelines and specifications for the support materials were formulated. From the situational analysis, many constraints to the learning of chemistry and regular implementation of practical chemistry work in schools, especially the less endowed communities, were identified. Some of these constraints were lack of proper laboratory guides or manuals, no or limited conventional equipment, lack of laboratories, large class size and time pressure, due to syllabi overload and examination demands. These kinds of constraints were also identified by Mafumiko (2006) in a similar research that he carried out in Tanzania. Literature review also highlighted the many benefits of micro scale chemistry and how it could contribute to solving some of the constraints discussed above. In this study, the above mentioned constraints featured as limiting factors to the building of chemistry concepts until the intervention introduced (the MCE), took care of all other envisaged constraints.

There were three main phases involved in data collection and execution of information from the gathered data. There was a pre-intervention phase where a diagnostic test was developed and administered to gather the pre-service teachers‟ naive ideas about the topics for the semester, the intervention phase which required the use of the MCE, and the post intervention phase where teacher-trainees‟ post-intervention performance was analysed and their impressions sought. The pre-intervention phase investigated whether the participants had any pre-conceptions or alternative frameworks about the selected inorganic chemistry topics. It also investigated how the introduction of the MCE approach would offer participants the opportunity for self-directed learning and correction of their alternative concepts. Participants" reaction towards the MCE was obtained through observation during practical sessions which involved the use of the MCE in the intervention phase. The observation schedule or curriculum profile particularly assessed their manipulative skills and dexterity with the use of the MCE. Finally, the effect of the MCE on the enhancement of the teacher-trainees" cognition and concept development was obtained through changed scores gathered from the post test. An action research design, does not allow a researcher to pre-empt a situation so as to direct a research situation. Thus, the outcome in such a research tells a situation as exactly as it appears with no biases. The choice of the action research design gave the Researcher full control over scheduling of MCE activity sessions. It also enabled the Researcher to aim at discovering solutions to the identified problems and to create new knowledge in her classroom (Reason & Bradbury, 2001; Gall, 2007).

**Research Population**

There are two types of population in research- a target population and an accessible population (Kirshenblat-Gimblet, 2008). The target population refers to the entire group of individuals to which a researcher is interested in generalising their conclusions. The target population for this study comprised all Science Education trainees of the University of Education, Winneba. This constituted all major and minor chemistry students (also to be called teacher-trainees in this study) of levels 100 to 300. The entire target population consisted of 207 trainees out of which 27 were females, while 180 were males. Out of the total population of 207 trainees, only 48 were trained teachers. That is, these 48 had obtained prior training as teachers from diploma or certificate awarding teaching institutions and had practised at teaching before enrolling to read science at the University of Education, Winneba. The remaining 159 trainees had no prior experience in teaching: they were all senior high school graduates.

All science education trainees at the University of Education, Winneba (UEW) who study basic inorganic chemistry and perform practical chemistry activities, formed the target population for this study. An accessible population in a research is the population to which the researcher can apply her conclusions. This population is a subset of the target population and is also known as the study population. The accessible population for this study, however, were all level 100 teacher-trainees who study chemistry as their major or minor courses in the Department of Chemistry Education. If a student is classified as a chemistry major trainee, it means that the student in question studies chemistry as a major subject and will graduate as a chemistry teacher. He/she will study another science discipline, such as Integrated Science, Biology or Physics, as his/her minor (second) subject. However, chemistry minor students read other science disciplines as their major subject, and read chemistry as their second subject. They may major in Biology, Physics or Integrated Science education.

## Sample

The sample for this study (the accessible group) was an intact class of 48 first year (Level 100) students. The entire group participated in the research at the University of Education, Winneba. This was a purposive group comprising 42 males and 6 females that was purposely chosen for the study. The term „purposive‟, as used in this study, meant that it was the Researcher‟s own class and so had complete control over events. Besides, it was purposely chosen because that was a chemistry class which comprised majority of trainees who had no prior knowledge about teaching and were also studying topics which easily lent to the use of the MCE. Only nine out of the research sample had prior experience in teaching at the basic school level while the remaining 39 had no prior experience in teaching. The nine trainees with prior experience in teaching already had the senior high school certificate as well as diploma degrees from diploma awarding institutions; the latter were all senior high school graduates. This class was chosen for the study because the Researcher was in charge of teaching chemistry to the group. All participants had to learn specific departmental required topics within the semester. Therefore, there were no exclusions as each participant had to learn the prescribed topics and perform the accompanying practical activities. This made it easy for the Researcher to organise the participants for the MCE activities. The ethics which govern educational research was read out and discussed with the participating teacher-trainees. Their consent was sought before the start of the research study. All these participants had passed the chemistry examination organised by the West African Examinations Council (WAEC) at the senior high school before their admission to the University of Education, Winneba. Participants in this study read other courses besides chemistry, such as the pedagogies of teaching chemistry, biology and physics.

**Phase 1: Pre-Intervention Activities**

**The diagnostic concept test**

Diagnostic concept tests are designed tiered multiple tests which have a trait for elucidating students‟ own ideas about science concepts. Some diagnostic tools are simple multiple choice questions, concept tests, interviews and dyads. In this study, a diagnostic test adapted from Treagust (2006) was used. The adapted diagnostic concept test, comprised 100 objective test items, based on the course for level 100 chemistry students. The diagnostic test comprised parts „a‟ and „b‟. Part „a‟ comprised 100 multiple choice items with four options while some of the items in part „b‟ consisted of short answer items. The test was prepared for assessing the teacher-trainees‟ own ideas or pre-conceptions about selected inorganic chemistry topics. A diagnostic test was chosen because diagnostic tools have the advantage of helping educators and researchers gain insight into conceptions held by larger samples of students (Treagust, 2006). The goal for designing such a concept test was to create a tool to identify chemistry teacher-trainees‟ concepts in relation to some topics in inorganic chemistry. The topics included acid-base strengths, types of reactions, stoichiometry (mole ratios), main group chemistry, the particulate nature of matter (PNM), hybridisation and skill management in the use of micro scale chemistry equipment for teaching. These topics were purposely chosen because practical activities on the selected topics could be carried out with the MCE. Besides, they were all topics which formed part of the junior and senior high school curricula and so are taught in the basic and secondary schools as well as science-biased universities. The topics chosen for use in this study were those that were to be of benefit to teachers and students at all levels of education.

The model for the concept test questions was adapted from Treagust‟s (2006) chemistry diagnostic test on chemical change and equilibrium of chemical reactions. The test items for this current study were on the mole concept (stoichiometry), periodicity, acid- base strength, hybridisation and the particulate nature of matter (PNM). Based upon Treagust‟s model, each item in the diagnostic test comprised two levels or tiers. The first tier was a factual multiple choice item. The trainees were supplied with optional answers from which they made a single choice. In the second tier of some questions, the trainees had to either choose or state a reason to further substantiate the choice that they made in the first tier. In other instances, they had to complete reasoning statements to support choices made in the first tier. The second tier was to find out if the trainees truly understood the choices that they had made in their first tiers. This was also to confirm or refute their choices. An important aspect of this concept inventory was its ability to identify alternative conceptions that the trainees held about basic inorganic chemistry concepts. Participants‟ responses to conceptual reasoning questions were used to identify their own prior concepts about the basic inorganic chemistry topics to be taught.

After validation and two try-outs, the 100-item diagnostic test was administered to the sample. The questions were all tiered resulting in 200 individual questions. Each main test question consisted of a lead multiple choice questions for which students had to make a choice from a range of optional answers. Then, they had to go to the second part (second tier), the reasoning part, to choose from a set of answers, the one which correctly explained their first choice (in the first tier), assuming it was correct. The second level or second tier items were posed to differentiate between trainees who scored well by chance in the first tier, and those who got high scores because they had a sound understanding of the concept being tested. The internal consistency of the diagnostic test, using KR-20, was 0.75, which was quite good (Streiner, 2003). The discrimination index was 0.32-0.60, while item difference was evaluated to be 0.12-0.65. A sample of the test items is shown in Appendix A.

Apart from merely distinguishing between trainees with sound understanding of concepts and those without it, the diagnostic test also brought out trainees‟ wrong concepts or ideas for correction and improvement. The test also helped to answer part of the research question for the study. First, a fact had to be established as to whether trainees truly had any misconceptions about the selected inorganic chemistry concepts, or not. The unscientific, alternative, concepts which were identified were worked on through an MCE intervention in phase 2 of the study.

**Exemplary MCE lesson plans/ manuals**

Curriculum materials were designed for teaching in this first phase so that they could be implemented in the intervention (2nd) phase. The design of curriculum materials has been found to be very useful instruments in the improvement and execution of concept based lessons (Powell & Anderson, 2002). Based upon information obtained from the situational analysis, a field trial, literature reviews on how students learn, how concepts are formed, and the effectiveness of practical activities, the following guidelines, based on the RADMASTE curriculum from South Africa, were formulated:

1. Active / generative and flexible learning
2. Simple and time-saving activities
3. Specific and achievable goals
4. Adequate content and pedagogical directives
5. Alignment with the overall curriculum schedule and design

The lesson materials were designed based on instructional principles propounded by Kolb, Boyatzis and Mainenelis (2001) and Gagne (1965). This was done so that the lesson materials could be student-centred and enable trainees to be actively involved in both hands-on and minds-on practical work in the classroom during their normal class lessons. The design guidelines ensured that trainees were motivated to work hard at their development of concepts through practical activities. Feedback was always given for further improvement of teaching and learning. The activities were all designed with the MCE in mind (Huang, 2007). Since the equipment were small, both in size and capacity, and use very little chemicals, the end results could be achieved in relatively shorter times than with standard or conventional equipment. This would also enable teachers to interact well with their students through discussions (Singh, McGowan, Szafran, & Pike, 2000). The time saved from the simple activities would allow or compensate for group work and good student-student as well as teacher-student interaction times.

The lessons were designed with few, but clear, learning objectives. This was to prevent the problem of cognitive overload in the minds of students. The objectives were to be explicitly achievable so that at the end of the lesson the teacher would be able to do a personal assessment on the achievement of his/her set goal. This reduced ambiguity to the barest minimum through the use of simple statements and clear instructions, since ambiguity in learning goals could result in confusion for both the teacher and the student, and result in the formation of alternative concepts.

The developed MCE-lessons contained adequate information required for lesson preparation and practical work. The MCE designed lessons for teachers also contained suggested, or model scientific, answers to pre-determined questions to help inexperienced teachers to assess their students‟ practical work in class as suggested by Taber (2002). The lessons were also designed with an intention to equip trainees with adequate manipulative skills in the use of the MCE so that they would be able to use the skills gained to perform concept-based activities later during their active days in the schools (Engida, 2012). These materials were all designed in line with the specified curriculum and course requirements of the University of Education, Winneba. This was to ensure that one stayed within the limits and requirements of what the university and the department stipulated for the pre-service teachers‟ training. The materials were again designed in a way such that their integration into lessons would not cause any delay in the execution of normal classroom lessons. The time allotted for each lesson was taken into consideration with respect to the scientific concept to be taught while using MCE activities. In this way, the MCE designed lessons fitted well into the departmental time allotted for teaching. The curriculum materials were tested for validity and practicality, as suggested by Mafumiko (2008) in his study in Tanzania, during the first semester of the UEW academic year.

**Design of exemplary students' activity sheets**

Almost the same guidelines, as was used for teachers‟ teaching manuals, were also used to prepare trainees‟ exemplary MCE work manuals (Gagne, 1965; Powell & Anderson, 2002). Trainees were required to formulate, validate and confirm through activity work. The objectives of the activities were clearly spelt out. In short, the trainees‟ manual or work sheet activities were designed with more emphasis on manipulation of ideas (process and concepts skills) than on manipulation of the already simple equipment. It had pedagogical features which encouraged students to assume responsibility for their own learning as well as to create a community of learners who engaged in open exchange of ideas.

These exemplary materials were also tested for validity, practicality and effectiveness. The face and construct validities were assessed after thorough scrutiny by senior chemistry educators and correlation between the items. The effectiveness of the designed exemplary materials was assessed by trainees‟ performance on a post-test that was administered after the intervention, as well as by the trainees‟ own opinions in a structured interview and a questionnaire. An example of the designed student work sheet is presented in Appendix G.

**Validation of the curriculum materials**

Curriculum materials are text books, syllabi, lesson plans, course manuals, and other resources, which help to interpret curriculum ideas in concrete terms in a classroom. Curriculum materials have the potential to facilitate reforms because they are concrete and tangible ways for embodying the essentials of a reform (Powell & Anderson, 2002). The curriculum materials for this study had to be validated to ensure that they were standard enough and could measure that for which they had been prepared to measure. Tasks required of the trainees were within the scope of the syllabus and scaffolded so as to test for all levels of understanding as observed with Bloom"s taxonomy. The validation was also to ensure that the kind of reform anticipated was incorporated, as suggested by Powell and Anderson. For these purposes, there was an initial try-out of the designed curriculum materials in the first semester with the participating class (sample) to assess its construct validity. Results from this try-out were used to revise the final curriculum materials, for the actual research in the second semester of the same class, in the Chemistry Department of the University of Education, Winneba. In the try-out, the design in Figure 5 of Chapter 2 was used to ensure specificity and validity of the intervention. Broad objectives for the MCE approach, and specific intended concepts to be developed, were also outlined. Resources and planned activities were all analysed in the context of the study"s desired goals. In the second stage, the desired curriculum activities that were to enable trainees to achieve the desired objectives were implemented. What trainees actually did in their tasks, using the MCE, to ensure that their mental actions matched their physical actions, were monitored through classroom discourses and the way they interacted with the curriculum materials during practical activities (Abdullah, Mohamed, & Hj Ismail, 2009; Abrahams & Millar, 2008). Finally, what the trainees learned as a consequence of using the MCE was measured in the post-test, at the post-intervention phase. There was a problem with management of time during practical activities in the validation period, but this was resolved in subsequent activities. Trainees were encouraged to read through their worksheets as well as the suggested reading text in their course manual prior to class. The validity, reliability and practicality of the research approach were all tested through the try-out before their final implementation in the second semester of the academic year in UEW.

Factor analysis was used in assessing the construct validity of the questions as it allowed for the selection of items that tapped the concepts to be measured (Ofori & Dampson, 2011). Data were obtained from the try-out through an observer evaluation questionnaire, an interview with the observer, a students" questionnaire, and a focus group interview with the trainees. The necessary amendments were made in both the approach and teaching/learning materials before their execution on the study sample (subjects), in the second semester of the academic year of 2010/2011. For example, 130 two-tiered test items were constructed and approved of by experts as worthy enough for finding out students" concepts on some chemistry topics. Upon trying them out, a few items were found to be ambiguous; while for others, the reasoning answers were not very discriminatory. Such questions were not used on the sample for the study. An additional challenge phase was included to enable the trainees to experience a contrast between their own concepts or predictions and what actually happened in the course of the practical activity. Hanson (2015), stated that "researchers may suggest cognitive conflict as a strategy to overcome misconceptions, but more is needed to help students develop accurate and well-functioning concept networks". A hypothetical-deductive learning cycle was suggested as a better alternative to the use of cognitive conflict. Both methods for concept change are addressed in this study. The try-out was carried out to ensure that the data collection instruments and curriculum materials were designed to measure that for which they had been constructed, and that they would be reliable and give about the same outcome each time they were administered. The reliability of the curriculum materials were found to be quite high, ranging between 76 and 87 %. Instruments for collection of data are found in Appendices A - H. One hundred (100) test items were selected for the actual study after all important considerations on their content validity and reliability were done.

**Reliability and validity**

Reliable measures can be relied on to produce consistent responses over time. In all the constructed tests and curriculum materials for the study, reliability was ensured. All other instruments were also tested for reliability and found to be reliable instruments and data for use. Validity of an assessment is generally gauged through examination of evidence in content, criterion, construct, and face (Cohen, Manion, & Morrison, 2011).

In this study, the WAEC examination syllabuses for Chemistry and Integrated Science for Senior High Schools were used as additional guides to ensure adequate reliability of the concept diagnostic test. This is because it was expected that since the chemistry teacher trainees would be teaching in the secondary and basic schools which required that the same topics be taught (though to various degrees), they had to master the concepts underlying the topics in the current study. The topics chosen for use in this study were those that were to be of benefit to both teachers and students at all levels of education. Besides, they formed part of the trainees‟ course topics for the semester. The constructed tests, which were adapted from Treagust (2006), were validated by three senior lecturers in the Department of Chemistry Education, of the University of Education, Winneba, as well as a senior teacher in a Senior High School. These assessors were chosen based upon their experience in the conceptual approach to teaching, as well as their years of experience in teaching. Both the face and construct validity of the test items were judged to be good by the assessors as a specification table built upon Bloom‟s assertions was used. In a similar vein, other the curriculum materials were also assessed and found to be valid and reliable by the same assessors.

**Administration of the Diagnostic Concept test**

The validated 100-item diagnostic inorganic chemistry concept test was administered to the participating class on the first day of their meeting with the Researcher. The importance of such a diagnostic test before the start of teaching and learning was explained to the participating teacher-trainees. These trainees were first educated on some methods for assessing learners, such as concept maps, multiple choice summative tests; open ended responses and interviews, as suggested by some researchers (Costu, 2008; Nyachwaya, et al., 2011). After other assessment methods had been discussed with the trainees, the singular benefits of chemistry- based diagnostic tests, which could diagnose their understanding of concepts, were explained to them (Tsai & Chou, 2002). This was to enable the trainees appreciate the diagnostic nature of the two-tiered test. How other researchers had used this diagnostic test with success in their chemistry classes were discussed with the sample. All the level 100 chemistry teacher-trainees at this point, obliged to take part in the study.

Participants were given enough education for them to understand what the research was all about and why it was important for teachers to understand their own conceptions as well as those of their students‟, concerning certain topics before teaching and learning commenced. The entire class of 48 first year (Level 100) inorganic chemistry trainees wrote the pre-test. Most of the participants were senior high school graduates who had weak passes in the national chemistry examination that they wrote before entering into the university. The entry grades of participants in chemistry ranged between grades B3 and C6, with more than half of the class having grades C4 to C6. Grade C indicates an average pass mark. The test was scored and analysed, while the identified misconceptions were classified into categories. In the multiple choice test only, each correct answer to a question attracted one mark. The second part of each question, which was the reasoning part, was not scored. The first set of multiple choice items of each question formed the single tiered questions. The single tiered questions were termed the multiple choice tests (MCT) in this study. The second part (tier) of the test plus the first part which is called the MCT altogether formed the two-tiered test. This was known as the two-tiered test (TTT). The second-tiered part was scored by giving a student a full mark if both parts of a question were answered correctly. If one part of the tiered question was wrong, the student was not awarded a score. These results were analysed and discussed.

After the administration of the adapted pre-concept diagnostic test (Appendix A), the participants were taken through an intervention based on their identified conceptual problems. The intervention was to adopt a concept-based teaching approach which culminated in a micro practical chemistry activity to enable participants to build their own concepts of the chemistry topics through personal experience. Participants undertook the MCE concept-based lessons and activities for ten weeks to study topics on periodicity, the particulate nature of matter, acid-base, mole concept, hybridisation and stoichiometry. The micro chemistry equipment and its manual (the accompanying adapted curriculum materials) were used as the intervention tools to correct the identified concept problems during the study period. The adapted curriculum materials were basically the lesson notes and suggested answers as well as student worksheets which had been modified from the South Africa RADMASTE micro chemistry educational materials. These adapted materials have been referred to as exemplary MCE lesson worksheets and manual in some cases because a collection of the materials constitutes a manual.

**Phase 2: Intervention**

**Lessons**

Curriculum materials have been known to facilitate reforms because they are concrete and tangible ways for embodying the essential ideas of a reform (Powell & Anderson, 2002). According to Schneider, Krajcik and Marx (2000), such materials clarify and support teaching and learning in educational settings, and provide novice teachers with introductory pathways and confidence in teaching. Thus, after the initial introduction of the micro chemistry equipment, subsequent lessons were all taught using the MCE and its accompanying manuals. The developed MCE-lesson manual contained all the necessary steps, ideas and equipment required for lesson preparation and practical work as compared to the traditional curriculum materials. The manual contained an introductory focus question which allowed trainees to think of their initial conceptions before carrying out an activity. This was followed by a challenging question which could cause a cognitive or conceptual conflict, if they had other alternative ideas about the chemistry concept under study. This conflict had to be solved through student labs, with further reflection on their outcome. Although each lesson lasted two hours, the practical activity (hands and minds-on) with the MCE lasted only one hour. A total of ten lessons, which involved the use of the MCE teaching materials, were taught. The first 30 minutes of each lesson was used to introduce the lesson through a concept quiz which was conducted as in normal traditional lessons. The concept quiz questions were carefully chosen to deliberately get the trainees to reflect on whatever concept was intended for that day‟s lesson. It was also to test whether participants had done their pre-class reading on the day‟s topic. Each pre-class reading assignment was carefully chosen to reflect the intended concept for that day‟s lesson. Each question was specifically based on a single concept. A short discussion around the intended concept of interest, followed by development of the lesson, then followed for about 20 minutes. The trainees were asked thereafter to go into their working groups to carry out the day‟s practical activity; which was based on the desired chemical concept of interest. The pre- and post-laboratory exercises were all done within the one hour that students had at their disposal to perform the MCE activities.

Portions of the MCE support material were revised and tailored to suit the needs of the participating class and the topics for that semester. Whenever the original RADMASTE resource materials contained unfamiliar foreign examples or procedures, which were not in line with the Chemistry Education Department‟s requirements, they were modified to suit the departmental requirements. Again, unfamiliar cultural settings were substituted with familiar examples, such as using phrases like cocoa farm, snail shells, and orange juice which Ghanaian students are more familiar with, instead of phrases like red cabbage (during acid-base titration). When an original MCE activity was structured to last for a longer period than the lesson would allow, then it was restructured to last for one hour only, as the lesson plan would allow. The MCE materials, as well as the equipment, were introduced to the class and thorough discussions were held before their use. Samples of the trainees‟ work sheets (from manual) can be seen in Appendix G. During the last 30 minutes of each period, there was a re-cap of the day‟s activities as well as whole class discussions to correct any lingering misconceptions that some participants still had and also to reinforce concepts that they had understood through other exercises.

The teachers" manual contained suggested accepted scientific answers to questions that were contained in the trainees" activity sheet. An example of a teachers" manual accompanying a student worksheet can be found in Appendix E. The concepts in the manual were explained in such simple words that teachers could themselves understand and easily guide their students to understand them as well. Other important hints that teachers would require to enhance both their pedagogical and content skills were also provided. The provision of hints was important since the participants were being trained to go out and teach and as such need to master all these process, manipulative and concept skills for their future use. A typical sample of a teachers" lesson sheet with answers is shown as Appendix H.

**Micro Chemistry Equipment Activities**

Trainees" performances on the MCE classroom lessons and activities were monitored, marked and scored. In particular, how they were able to manipulate the simple micro equipment with dexterity, to enhance their conceptual understanding of chemistry principles, was what was observed. For example, trainees were expected to be able to set up required apparatus, demonstrate the skills required with the use of each piece of equipment and if they were used appropriately for the designed activity. On the observation check list (Appendix B), there was a portion that assessed how well the trainees interpreted instructions and implemented them practically, in order for them to understand the principles that were taught. It was expected that adequate knowledge and expertise in the use of the MCE was going to be translated into knowledge gain in chemical concepts. It was also expected that trainees would be able to extend the knowledge gained from the use of the MCE in concept development (through transference) as suggested by Akella (2010) to their various work places after training. That is, they should be able to apply the principle (that is conducting concept-based practical activities for acquisition of knowledge) of using micro low-cost equipment and consumables in various ways to enhance the concept development of their students through the use of local resources. The data obtained was then analysed qualitatively and quantitatively to assess trainees‟ progress in their engagements with the MCE.

**Observation**

Trainees‟ interaction with the designed worksheets and micro equipment were observed and rated with the help of a designed observation schedule to find out if pre-desired skills and concepts were being acquired. Each group (a pair of trainees) was observed for 30 seconds. The Laboratory technician who had been trained through video lessons on classroom observation and practical sessions in other lessons, prior to this study, also made his own personal observations to corroborate that of the Researcher. He observed each group for 30 seconds. An inter-rater value of 92% was obtained when score sheets of the observer and technician were analysed for similar scored items.

**Phase 3: Post intervention phase**

A concept post-test, an observation check-list, a questionnaire, and interview instruments were used to collect corroborative data for the study. The post-concept test was to gather information on the effectiveness of the intervention. The observation check-list contained a set of statements which was used in the course of a lesson to monitor trainees‟ classroom practices and interaction with the MCE materials in a structured manner. The questionnaire contained a list of questions which gave each trainee the opportunity to comment on their own experience with the MCE in the study. The essence of the interview in this study was to probe further into trainees‟ ideas on pertinent issues which resulted from analysis of the questionnaires for the purposes of corroboration. These can be found in Appendices A, B, C, and D respectively. The diagnostic concept test was administered to assess the participants‟ gains in concept cognition. The post-interview and questionnaire items were used to gather the participants‟ opinions about the MCE intervention. They were also used to find out if participants would be able to apply and transfer their new knowledge gained to solve similar problems in future. The effectiveness of the MCE was tested through the post-test and its outcome. Trainees‟ opinions were also used to consolidate the assessment of the effectiveness obtained from the diagnostic concept test. Examples of the curriculum material can be found in Appendices E and F.

**Instrumentation**

This research employed six data collection instruments, namely, pre- and post-diagnostic concept tests, MCE designed lessons and practical activities, interviews, student questionnaire, teacher‟s log book and an observation check list (Hsu & Stanford, 2010; Kirshenblat-Gimblet, 2008). The pre- and post-tests were to provide quantitative information on the trainees‟ gain in conception (cognition) as well as how their views on science concepts altered after the introduction of the MCE. The interviews and students questionnaires were to collectively solicit trainees‟ views about their own observations and impressions about the intervention used–the MCE. The interview was particularly to allow trainees to express themselves even further than they could have done on their responses to the structured questionnaires. The teacher‟s logbook and observation sheet helped the teacher to also record and assess whether intended behaviours were being exhibited by trainees during their practical work, as well as to record important incidents worth commenting on. Here, accounts on the use of the MCE in enhancing concept development, were sought by the Researcher from her own observations and analysis of concept tests, and participants‟ so as to be able to collate the research outcomes. Thus different instruments were employed to enable the researcher gather as much information as possible in the course of study.

All these instruments were necessary since triangulation of data from different instruments enhances corroboration of findings (Cohen, Manion, & Morrison, 2011). However, the order in which they were administered were:

1. Pre-intervention test (Collection of Pre-MCT and Pre-TTT data)
2. Design of MCE-based curriculum materials and activities
3. Treatment period (Lessons and MCE practical activities)
4. Observation schedule (for collection of data on engagement with MCE)
5. Post-intervention test (Collection of Post-MCT and Post-TTT data)
6. Questionnaire (to collect data on engagement with MCE and understanding)
7. Semi-structured interview schedule (to collect data on trainees" opinions)

Presented in Table 1 is an overview of the data collection methods and related research themes.

**Table 1**: **Data Collection Techniques and Data Sources**

| Data Collection Techniques | | | | | | |
|---|---|---|---|---|---|---|
| Data sources | Pre-test | Post-test | Classroom activities | Observation | Interview | Student learning |
| Pre-diagnostic concept test | √ | | | | | √ |
| Lesson notes | | | √ | | | √ |
| Practical activity | | | √ | √ | | √ |
| Observation checklist | | | √ | √ | | √ |
| Researchers" Logbook | | | | | | √ |
| Post-test | | √ | √ | | | √ |
| Questionnaire | | | | | | √ |
| Semi-structured Interview | | | | | √ | √ |

How each of these methods or instruments in Table 1 was used to collect data from required sources for the research is discussed in the next sections.

**Data Collection Techniques**

Data collection is an important aspect of any research study. It is the process of gathering and measuring information on variables of interest, in an established systematic fashion that enables one to answer stated research questions, test hypotheses, and evaluate outcomes. The data collection component of research is common to all fields of study, including the physical and social sciences. Accurate data collection is essential to maintaining the integrity of a research. Data collection is necessary as it ensures that data gathered are both defined and accurate, and that subsequent decisions based on arguments embodied in the findings are valid (Ofori & Dampson, 2011).

**Classroom observation schedule**

A structured curriculum profile (also known as observation schedule or checklist) was drawn up to aid the observation of student activities (Hofstein, 2004; Hofstein, Shore, & Kipnis, 2004) A curriculum profile is a set of statements about a selected personnel‟s activity in the course of a lesson. Items on this schedule help in the monitoring of classroom behaviours and interactions in a structured manner. Most observation schedules observe teachers and their instructional strategies. However, this particular profile, unlike most common observation schedules, was designed to assess trainees‟ classroom practices during the MCE practical lessons. Its focus was mainly on how aspects of the lessons were executed and if expected or desired results were being achieved at various stages of the lesson. It was also to find out if trainees could discuss their MCE results coherently and draw logical conclusions from their discussions. This section of the observation schedule was based on measurement of alertness (Munde, Vlaskamp, Maes, & Ruijssenaars, 2012) and ability to use evidence to generate knowledge. The conceptual framework for this instrument was the student-mediating paradigm, which maintains that students actively process information and interpret classroom reality (Yoo, Hong, & Yoon, 2006). This enables a researcher to collect students" classroom process data in the context of on-going instructional learning processes. The schedule allowed the Researcher to focus on individuals and groups of trainees for about 30 seconds each and recorded her observations.

Observations were made about participants" initial response during the introductory, developmental and concluding portions of the MCE lesson for each of the 10 lessons taught. Some of the observed actions were their interactions with their colleagues, types of materials they interacted with, specific actions they engaged in with the teacher and their colleagues, the language used and if they were able to link their conclusions to the set objectives or conceptual ideas. Their manipulative skills with the micro equipment were also observed. However, it was a little bit difficult; to observe and record interesting episodes into the teacher"s logbook. Thus, a laboratory technician was trained to also record classroom observations which were compared with the researchers" and discussed shortly after closure of the day"s lesson for the purposes of reliability and triangulation (Ofori & Dampson, 2011). Prior to this study, the technician was introduced to various modes of observation, by watching videos of such activities and understudying the researcher as she made observations in other classes. He was then given the chance to make a couple of observations in conjunction with the Researcher, prior to this study, which was followed with comparison and discussion to affirm or refute certain remarks he had made. All this training was given to the technician to enable the collection of proper observation data for the purposes of corroboration, in case the researcher missed episodes worth noting. A special mode of scoring trainees‟ acquisition of skills and expressions of conceptual understanding, was adopted from Mafumiko‟s (2006; 2008) work on the use of MCEs in secondary schools in Tanzania, where he used the symbols: +, ±, and – to indicate whether an activity was observed or not. How this was used is illustrated in the observation schedule (Appendix B). An inter-rater reliability was estimated by checking the percent agreement of items or categories on the Researcher and the laboratory technician‟s observation sheets.

The curriculum profile list used to assess how trainees‟ interaction with the MCE materials affected their understanding of concepts. A check list helps to paint a picture of how intentions are put into practice. In this study, it helped to draw a corroboration of findings between the structured interview and the student questionnaire, as well as in the interpretation of student test data, just as it did in studies done by Motswiri (2004) and Mafumiko (2006). The check list used in this study assessed trainees‟ activities in class, with respect to how they acquired learning skills, and how they demonstrated understanding of principles and formed concepts. Responses to indicators would reflect the relationship between the use of the MCE and an apparent demonstration of concept development. Trainees‟ classroom discourse (that is responses and other classroom experiences) was also used as a measure of their demonstration of understanding of concepts and progress in their cognitive responses.

Brief notes on important actions that were made, but not part of the observation schedule, were noted in the teacher or researcher‟s logbook. Hofstein (2004), suggested other ways of assessing students‟ laboratory work to find out if conception is being made, apart from paper and pencil tests. He suggested a continuous assessment of rating regarding specific preconceived criteria and marking scheme in the course of one‟s observation (Hofstein, Shore, & Kipnis, 2004). Eight out of the ten lessons on MCE experiments were observed and recorded. These lessons were selected because they easily lent themselves to the MCE intervention so that the effect of MCE on concept development could be assessed. Data obtained from the curriculum profile and the researcher‟s logbook complemented each other. Items on the designed schedule for this study helped the Researcher to monitor classroom behaviour and interactions in a structured manner. Analysis focused on the trainees‟ ability in conducting classroom activities based on instructions at various stages of the lesson.

**Interviews**

A research interview is a prominent data collection procedure. It is a social interaction in which an interviewer initiates and controls a verbal exchange in order to obtain information that is relevant to an emerging or previous theory (Ofori & Dampson, 2011). Interviews are a systematic way of talking and listening to people so that one can collect data through conversation. Interviewees are able to discuss their perceptions and interpretations regarding a given situation (Gray, 2004). The essence of the interview in this study was to probe further into trainees‟ ideas on pertinent issues which resulted from analysis of the questionnaires. It was also to validate observations made during the classroom MCE lessons. According to Krathwohl (2009) and Mafumiko (2008) interviews and questionnaires complement each other. Krathwohl added that interviews provide in-depth information collected through the questionnaire and classroom observations. Four foci groups consisting of 12 trainees each were interviewed one week after the last MCE intervention lesson. The first 24 trainees, as well as the last 24 trainees on the class roll, were selected for the interviews in two separate sets (12 trainees per set) over a 4-day period. The time lapse between the last MCE lesson and the interview was to give them adequate time to reflect on the MCE lessons that they had. The focus interview (Appendix D) was semi-structured so that questions could be altered or expanded whenever necessary to enable participants to express themselves freely. Each interview was audio recorded and transcribed. A summary of key issues was noted to enable the Researcher to improve on them during a review of subsequent curriculum materials. Data from the open-ended questions and interview were put into themes and analysed qualitatively. Original quotes were used in the compilation of data, to give greater emphasis to some trainees‟ assertions and to illustrate important findings.

**The Student questionnaire**

A questionnaire is a research instrument which consists of a list of questions and other prompts designed to collect specific information for the purpose of gathering information from respondents. Questionnaires have advantages over some other instruments in that they are cheap, do not require as much effort, from the questioner, as in verbal or telephone surveys, and often have standardized answers that make it simple to compile data. Student questionnaires give each student the opportunity to comment on their own experience of being a learner in a course or research study (Cohen, Manion, & Morrison, 2011). The student questionnaire (Appendix C) used in this study was designed to gather information on students‟ experiences and opinions about learning chemistry education with the MCE approach. It assessed the usefulness of the micro equipment in enhancing their understanding of underlying concepts. The questionnaire consisted of 27 close-ended items and six open-ended items organised into three sections. A Likert scale was used to gather data in the first section of the questionnaire. The Likert scale ranged from an increasing value of desires from one (1) to five (5); where 1 = strongly disagree, and 5 = strongly agree. The first section assessed participants‟ impressions about the effect of the intervention (MCE) on their gain in knowledge and understanding of concepts. In addition, it assessed changes in their laboratory skills.

The second section consisted of six (6) open-ended items. Here, trainees could freely express their likes and dislikes about the MCE, and if they would recommend for its adoption fully in UEW, as well as its introduction into the basic and senior levels of secondary education, or not. They were free to express themselves and write any comments that they wanted on the MCE approach that they had experienced. The third section comprised another set of close-ended questions where participants were expected to express how useful or not that the MCE was with respect to laboratory sessions. They were also to describe in the form of a 5-point Likert scale how useful or not pre-lab sessions, focus /prediction questions, and post-lab questions contributed to their understanding of concepts. This third part of the questionnaire was developed by the Researcher based on comments received from students in the try-out questionnaire. The entire instrument was administered at the end of the MCE intervention where all the participants completed the questionnaire.

The data gathered on the questionnaires was analysed quantitatively by calculating the mean and standard deviation for each item on the trainees" understanding capability with the MCE approach. SPSS version 16.0 was used for the analysis. The internal consistency of the questionnaire was found to be 0.76 by Cronbach"s alpha, which is deemed acceptable, as similar constructs were measured. Cronbach's alpha is a measure of internal consistency; that is, how closely related a set of items are as a group. Data from the open-ended questions were also put into themes and analysed qualitatively.

**Students' pre-diagnostic and post concept test**

An adapted diagnostic concept test (Treagust, 2006; 2010) comprising basic questions on acid-base reactions, the mole concept (ratios), stoichiometry, periodicity and the particulate nature of matter (PNM) was administered. The tests were validated and their reliability tested (by using KR-20) before they were administered as standard questions for use. The item difference was 0.12 - 0.65, with discrimination values of 0.32-0.60. A sample of the diagnostic concept test is presented in Appendix A.

Apart from merely distinguishing between trainees with sound understanding on concepts and those without it for improvement, the diagnostic concept test also brought out students" wrong concepts or ideas. The diagnostic test helped to answer part of the research question for the study. First, a fact had to be established as to whether trainees truly had any misconceptions about the selected inorganic chemistry questions or not. The unscientific, alternative concepts were then identified and worked on through an intervention. It was expected that the trainees would acknowledge their short-comings, if any, and then use evidence collected from MCE activities to correct their initial unscientific ideas during the intervention. A similar set of concept diagnostic test items as those which were administered as a pre-test were again administered as a post assessment test to find out the effectiveness of the MCE as an intervention tool which could enhance students" conceptual understanding and cognition. The trainees" differences in the one-tiered (MCT) and two-tiered (TTT) parts of the tests were analysed for correlation to find out if their performance in the two tiers had any linkages.

**Logbook**

A logbook is a record book of day-to-day experiences in a research study. In research, such a record acts as a backup to observations and other instruments used in collecting data (Wright & London, 2009). In this study the Researcher‟s logbook was a record book kept for the purposes of recording events which could not be captured on the students‟ observation list but was necessary for discussion if exhibited. It also allowed for record keeping of events of interest which cropped up in the course of the MCE lessons, but were not in the designed lesson plans. These records were used to augment data obtained from the observation check list. Information obtained was also used for the revision and improvement of future MCE lesson plans. Some of the recorded events were formulated into some of the items in the structured interview guide.

**Ethical Issues**

In this study, ethical issues for both quantitative and qualitative (social) research were all taken into consideration since the study is a mix of both. Participants were adequately briefed about the research and their consent asked for before the start of the semester‟s work. The purpose of the research and its long term benefits were thoroughly explained to them. The difference between consent and informed consent was explained to them so that they could make an informed decision. The participants were also assured of confidentiality after the implications of the study and their involvement in it were explained to them. Thus, there has been no individual identification or responses ascribed to an individual in any way in this write up. Participants were assured that they could read and comment on the draft report for inadvertent misrepresentations of persons or situations.

In order not to implicitly infringe on the rights of privacy of participants the classroom climate was created to be one where participation was made as pleasant and as easy as possible. They were also given the assurance that since the study was conducted in the course of their normal semester, it was in no way going to compromise the content they had to learn or the number of weeks that they had to study or any curricular activities that had to be performed for that semester. They would be acknowledged for their participation and contribution towards the completion of the study.

**Data Collection procedure**

Permission was sought from the Dean of the Faculty of Science Education, of the University of Education, Winneba as well as the Head of the Department of Chemistry Education for the Researcher‟s students to be part of this study. The Researcher‟s students (teacher-trainees) who formed the sample were taken through the ethics of research so that they could make their own personal decisions to be part, or not, of the whole class study. The purpose of the study was explained to the trainees and their consent sought verbally. They were assured of anonymity and confidentiality. The laboratory technician (observer) was also briefed about the role the Researcher intended him to play during the study. He was also educated on the ethics of research so that he could be aware of his own rights as well as the rights of the trainees in the study. He was then educated on how to score the trainees‟ curriculum profile (observation) sheet through video presentations and „on the ground‟ practice in real classroom situations. Through verbal discussions and video displays he learned the skills required for detailed lesson observations and recording. During our observation sessions, each group was observed for 30 seconds and a maximum of one minute if controversial issues were going on within the group (which was quite rare, and occurred two times only). The inter-rater reliability, which was 92%, was obtained by calculating the percent of agreement between us (the raters). In most cases, we checked the same categories on our observation sheets.

First of all, a pre-intervention test was administered from which data on the trainees‟ misconceptions were gathered. This was followed by a treatment phase with the MCE materials, the use of the observation schedule to assess how the trainees used the MCE to build their own concepts, the administration of a questionnaire to gather their opinions about the intervention (MCE) and lastly, a post-intervention test to assess the cognitive impact of the treatment. The test items were basically multiple choice items and so choices made by the trainees were determined for ambiguity and difficulty. In the pre-test, it was not necessary to find out if objectives were covered, but this was done for the post-intervention test. Statistics were then generated for the scored questions. An index of discrimination, the difference between the percentage of high achieving students who got an item right and the percentage of low achieving students who got the item right were worked out. When half or less of the sum of the upper group plus the lower group answered an item correctly, the maximum possible discrimination was the sum of the proportions of the upper and lower groups who answered the item correctly. The statistical significance of the index of discrimination would have been to compute standard errors but this was not done as scores were run with SPSS (factor analysis). The reliability of the index of discrimination could be determined by correlating the pairs of values from the two test analyses. A semi-structured interview was conducted after the questionnaires were analysed, for the purposes of corroboration. The reliability command (SPSS) was used to compute Cronbach‟s alpha to check the dimensionality of the scale which was used for the questionnaire items.

**Data Analysis**

Data obtained from the diagnostic concept tests, MCE class discourse, classroom observations, students" questionnaires, interviews, and the teacher"s logbook were analysed for a more comprehensive overview of the study. The concept tests were analysed statistically with SPSS (version 16.0) to find out if trainees made gains in their post-intervention test (also referred to as post-test) performance after the MCE intervention. Trainees" performance on the two tiers were rated against each other through simple comparisons of their pre- and post-tests as well as the MCT and TTT results and then as frequencies. Paired samples tests were also run, by using the SPSS V. 16.0 software to find out if significant gains were made in the performance of trainees after they used the MCE.

The trainees" changed scores were subjected to correlation studies to find out if there were any linkages between one"s performance in the MCT and their performance in the TTT. The depth of explanation given to conceptual questions by trainees to demonstrate understanding of concepts, and how they discussed conceptual issues with their colleagues during practical activities in the classroom were analysed qualitatively to find trends and interpretations. Matters arising out of the MCE classroom exercises were analysed qualitatively. The MCE practical activities were, however, assessed quantitatively to ascertain their progress with the MCE within the study period. The classroom observations were analysed by simple counts of the positive, partial and negative indicators. Interviews and questionnaires were analysed by finding out means of scores on the Likert scale. The obtained responses were polled into two main responses for easy analysis of obtained data. All „agree" and „strongly agree" responses were pooled together as „positive" or „easy" responses in some cases while all „ not sure", „disagree" and „strongly disagree responses" were pooled together as „negative" or

„not easy‟ responses. The test data was again analysed using SPSS version 16 in order to obtain more analysed information on the trainees‟ performance. A correlational analysis on trainees‟ changed scores was further carried out to determine whether or not the two variables- changed scores in one-tier and changed scores in two-tiered tests were correlated. This analysis was employed because correlation studies look for variables that seem to interact with each other, so that when one changes, you have an idea of how the other will change. It explores the cause and effect (causal study) linkages among groups and elements. It varies between +1 and -1. A value close to +1 indicates a strong positive correlation while a value close to -1 indicates a strong negative correlation. A value near zero shows that the variables are uncorrelated. In this study, the trainees‟ performances in assigned tests were correlated to identify linkages. Results are presented in the next chapter.

Trainees‟ opinions, their experiences, and what they said they learned are also discussed. Part of their experiences was gathered through the use of a five-point Likert scale with the ratings 1= strongly disagree, 2= disagree, 3= not sure, 4= agree and 5= strongly agree. Ratings 1-3 were collated as unfavourable or negative responses while ratings 4 and 5 were pooled as favourable responses for easy analysis of results. For the purpose of confirmation of their opinions, qualitative results from the semi-structured interview were used to corroborate or refute assertions made in their questionnaire. The teacher‟s logbook was also used to further corroborate or refute questionnaire results and classroom observations.

**Summary of Chapter Three**

This chapter presented the design and implementation of the Micro Chemistry Equipment (MCE) at the University of Education, Winneba. The impact of the MCE activity was assessed after the actual implementation of the intervention, opinion and experiences of students, and their actual learning outcomes as well as its impact on their cognitive skills.

Data obtained from the diagnostic pre-and post-intervention tests, observation, questionnaires, interviews, and hands-on activities were collected for qualitative and quantitative analysis. The study employed both qualitative and quantitative methods to allow the Researcher to develop an overall picture of the intervention. This combination made an in-depth exploration of trainees" ideas about the MCE intervention easily possible.

# CHAPTER FOUR

## RESULTS AND FINDINGS

### Overview

In this chapter, the data obtained from the various instruments used in the three phases of the study have been presented with respect to the formulated research questions (RQ). The data have been presented in tabular and graphical forms, as well as identified themes, based on classroom experiences of the trainees.

### RQ 1:What types of concepts, in inorganic chemistry, would trainees come out with on the two-tiered test?

The adapted diagnostic concept tests which were based on Treagust‟s (2006) model comprised 100 objective test items, culled from the course for level 100 chemistry students. Each question in the diagnostic test comprised two levels or tiers „a‟ and „b‟. Part „a‟ was 100 multiple choice items, with between two to four options, while part „b‟ of the test comprised some short answer items. Part „a‟ of the tiered test was called the Multiple Choice Test (MCT). This formed the first tier of the two-tiered test. The first tier was a factual multiple choice item. The trainees were supplied with answers from which they made a single choice. The second tier was to find out if students truly understood the choices that they had made in their first tier. It was to confirm or refute their choices in the first tier. In the second tier of some questions, the trainees had to either choose or write a reason to further substantiate the choice that they made in the first tier. In other instances, they had to complete reasoning statements to support choices made in the first tier. This second part („b‟) assessed trainees‟ in-depth understanding of scientific concepts and was termed the two tiered section. The scoring of the pre-intervention concept test was done in two ways. A correct answer for each of the test items attracted a score of one. The total score on the test was 100. As indicated earlier, the second tier plus the first tier formed the Two-Tiered Test (TTT) or Two-Tiered Section. In both cases, 48 students answered the pre-intervention concept tests.

The raw scores of the pre-intervention or diagnostic concept test for the first tier or part „a" only of the test, termed the MCT, are presented in Table 2. This data was gathered in the first or pre-intervention phase of the study.

**Table 2: Raw scores of trainees in a pre-diagnostic multiple choice test (N=48)**

| Student No. | Pre-test score | Student No. | Pre-test score | Student No. | Pre-test score | Student No. | Pre-test score |
|---|---|---|---|---|---|---|---|
| 1 | 60 | 13 | 52 | 25 | 70 | 37 | 80 |
| 2 | 57 | 14 | 60 | 26 | 60 | 38 | 51 |
| 3 | 54 | 15 | 61 | **27** | **48** | 39 | 67 |
| 4 | 67 | 16 | 60 | 28 | 55 | 40 | 75 |
| 5 | 67 | 17 | 55 | 29 | 60 | 41 | 61 |
| 6 | 56 | 18 | 61 | 30 | 57 | 42 | 56 |
| 7 | 55 | 19 | 50 | 31 | 57 | 43 | 57 |
| 8 | 60 | 20 | 66 | 32 | 64 | **44** | **41** |
| 9 | 55 | 21 | 50 | 33 | 60 | 45 | 63 |
| 10 | 54 | 22 | 50 | 34 | 72 | 46 | 63 |
| 11 | 62 | 23 | 55 | 35 | 61 | 47 | 55 |
| 12 | 62 | 24 | 64 | 36 | 64 | 48 | 78 |

Mean Pre-MCT=**59.77**

From Table 2, it is evident that 46 trainees out of 48 passed the pre-concept test, with a pass mark of 50. Two trainees (shown in bold) obtained lower marks in the tests.

Major Finding 1

| Majority of the trainees (46 out of 48) passed the test in the MCT section with a mean score of 59.8%. This is an apparent indication of their understanding of the concepts. |
|---|

The responses of the pre-test in the multiple choice section of the first phase were analysed and presented in terms of the scientific concepts tested and the numbers of trainees who got the desired concepts correct. A detailed outcome of the identified alternative conceptions is presented in Appendix I. In all, 6 major misconceptions on acids, 6 on periodicity, 4 on chemical bonds, 6 on equations, mole and stoichiometry, and one each on pH, particulate nature of matter (PNM), hybridisation and solubility, were identified. The summarised report of the trainees‟ correct and wrong concepts are presented in Table 3, in terms of numbers and percentages of trainees getting the concepts correct, wrong, or showing no response.

**Table 3: Trainees' results of scientific concepts tested in the MCT (N=48)**

| Scientific concepts tested | Acceptable responses | Wrong responses | No response |
|---|---|---|---|
| Acid-base strength & reactions | 23, (47.92%) | 20, (41.67%) | 5, (10.42%) |
| Periodicity | 22, (45.83%) | 22, (45.83%) | 4, (8.33%) |
| *Chemical bonds* | ***38, (79.17%)*** | *10, (20.83%)* | *0, (0.00%)* |
| Equations, mole, stoichiometry (EMS) | 22, (45.83%) | 19, (39.58%) | 7, (14.58%) |
| *pH* | ***25, (52.08%)*** | *15, (32.08%)* | *8, (16.67%)* |
| *Particulate nature of matter (PNM)* | ***32, (66.67%)*** | *12, (25.00%)* | *4, (8.33%)* |
| Hybridisation | 21, (43.74%) | 16 (33.33%) | 11, (22.92%) |
| Solubility | 19, (39.58%) | 21, (43.75%) | 8, (16.67%) |

Note: Figures in brackets are percentages

In Table 3, it is observed that the number of trainees who gave responses that was acceptable, were below half the sample for five out of the eight concepts tested. This means that most students did not understand the five concepts, which were acid-base, periodicity, equations, mole, and stoichiometry (EMS), hybridisation and the solubility concepts. They fared poorly, especially in the concepts on „solubility" and „hybridisation". Majority of the students showed understanding for only three of the concepts, which were chemical bonds, pH, and PNM (in italic). The trainees" understanding of the eight concepts under study, as presented above, is shown graphically in Figure 10.

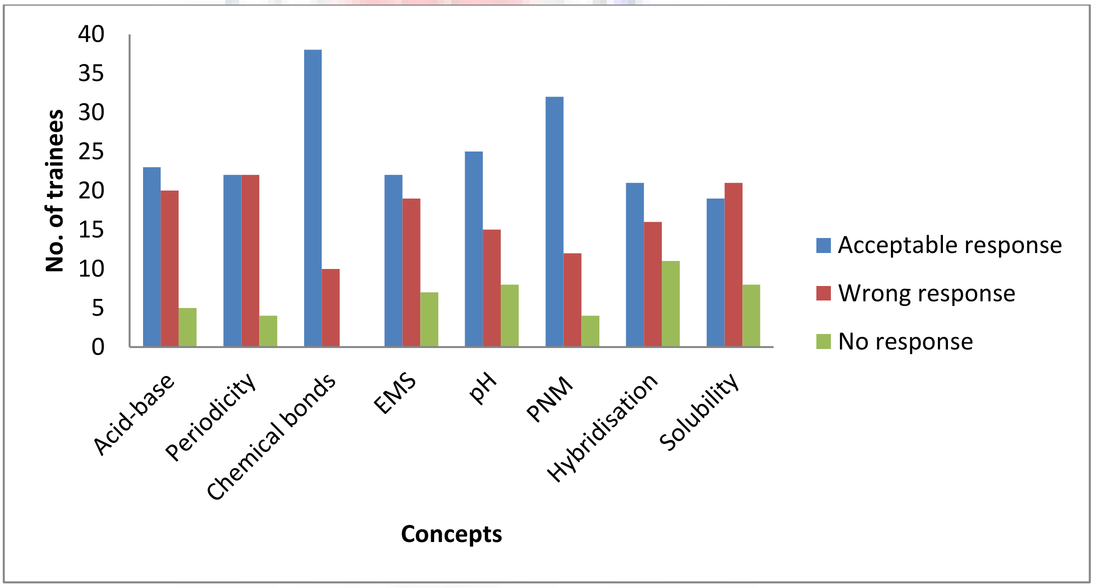


**Figure 10: Trainees' prior understanding of concepts MCT**

Major findings from Table 3 and Figure 10 are presented.

Major Finding 2

| |
|---|
| Majority of the trainees did not show conceptual understanding of most basic chemistry concepts, especially *solubility* and *hybridisation*. They had high scores in only three concepts out of eight; namely, chemical bonds, pH, and the particulate nature of matter |

The second part of the test required of trainees to exhibit understanding of some chemistry concepts by choosing or giving correct reasons to chosen responses in the multiple choice section (or first tier) of the diagnostic test. Here, trainees were expected to make correct responses in both parts of a question to gain a full score of one mark. The total mark for the entire test was 100 marks for the 100 diagnostic concept items. If a trainee got one part of an item correct and the other part wrong he did not get a mark at all. There were no half marks in the scoring of the two-tiered items. One had to get both parts of an item correct to get one mark. The responses of participants on the two-tiered test have been analysed in terms of marks scored on the test and the results displayed in Table 4.

**Table 4: Raw scores of trainees' performance in the pre-two tiered test (N=48)**

| Trainee No. | Pre-test score | Trainee No. | Pre-test score | Trainee No. | Pre-test score | Trainee No. | Pre-test score |
|---|---|---|---|---|---|---|---|
| 1 | 36 | 13 | 26 | 25 | 40 | 37 | 44 |
| 2 | 30 | 14 | 30 | 26 | 32 | 38 | 32 |
| 3 | 38 | 15 | 34 | 27 | 28 | 39 | 48 |
| 4 | 40 | 16 | 48 | 28 | 28 | **40** | **56** |
| 5 | 42 | 17 | 28 | 29 | 38 | 41 | 36 |
| 6 | 36 | 18 | 38 | 30 | 34 | 42 | 38 |
| 7 | 26 | 19 | 28 | 31 | 30 | 43 | 40 |
| 8 | 34 | 20 | 36 | 32 | 38 | 44 | 24 |
| 9 | 28 | 21 | 26 | 33 | 26 | 45 | 30 |
| 10 | 30 | 22 | 28 | 34 | 44 | 46 | 34 |
| 11 | 38 | 23 | 20 | 35 | 32 | 47 | 26 |
| 12 | 36 | 24 | 34 | 36 | 36 | 48 | 38 |

Mean pre-TTT= **34.21**;

From Table 4 it is observed that majority of trainees (47 = 97.9%) scored marks below the accepted pass mark of 50%, for the same pre-intervention diagnostic test used as MCT. Only one trainee (shown in bold) scored above 50% when the TTT scoring mode was employed. The overall mean for the class in the two tiered test was 34.21.

Major Finding 3

Almost all the trainees (97.9%) performed poorly on the conceptual reasoning part of the diagnostic test with a mean mark of 34.2%.

The eight chemistry concepts tested in the two tiered test were analysed and presented in terms of number and percentage of trainees who got the concepts correct, wrong or indicated no response. The results are presented in Table 5. The detailed responses for the identified alternative concepts can be found in Appendix J.

**Table 5: Results of the pre-two-tiered test (N=48)**

| **Chemistry concepts tested** | **Trainees with acceptable responses** | **Trainees with wrong responses** | **Trainees with no response in part 2** |
|---|---|---|---|
| Acid-base strength & reactions | 16, (33.33%) | 23 (47.92%) | 9 (18.75%) |
| Periodicity | 12 (25%) | 22 (45.83%) | 14 (29.17%) |
| *Chemical bonds* | *20 (41.67%)* | *28(58.33%)* | *0 (0.00%)* |
| Equations, mole, stoichiometry | 18 (37.50%) | 18 (37.50%) | 12 (25.00%) |
| pH | 16 (33.33%) | 20 (41.67%) | 12 (25.00%) |
| PNM | 21 (43.74%) | 20 (41.67%) | 7 (14.58%) |
| Hybridisation | 13 (27.08%) | 11 (22.92%) | 24(50.00%) |
| Solubility | 10 (20.83%) | 25 (52.08%) | 13(27.08%) |

Note: Figures in brackets are percentages

In Table 5, it is observed that the number of trainees who got the tested concepts correct were lower than those who got the tested concepts wrong or those who left the items unanswered. The percentages of wrong responses and no responses put together were high for concepts on periodicity (75%), hybridisation (73%) and solubility (79%). The high percentages associated with wrong and no response results meant that the underlying concepts required for proper understanding in basic inorganic chemistry were not well grasped by the trainees. The observations from Table 5 are presented graphically as Figure 11.

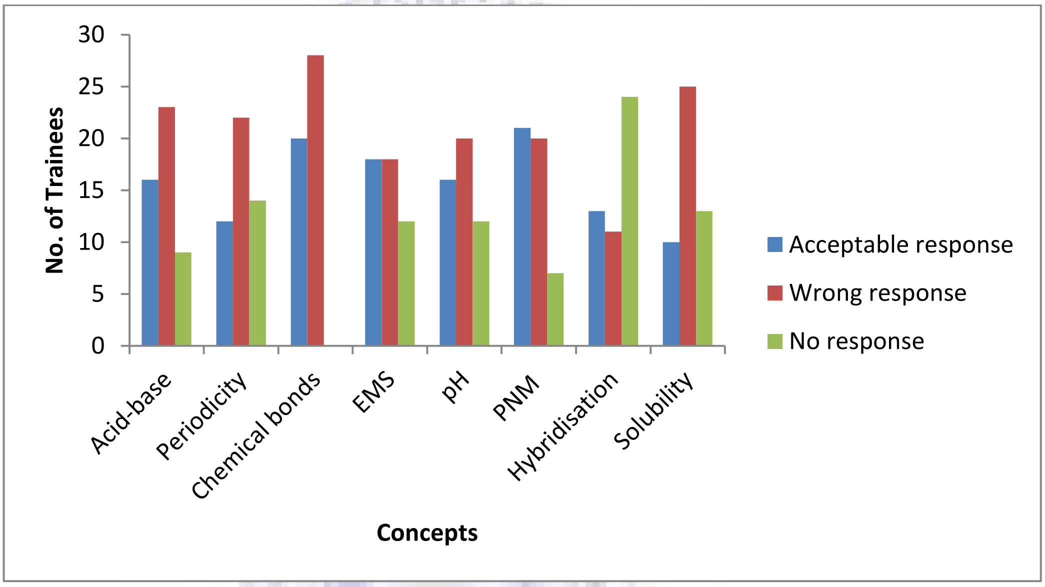


**Figure 11: Polled TTT responses of trainees' performance in the eight tested concepts as percentages**

As indicated earlier, numbers of trainees with both „wrong" and „no response" answers have been pooled together and matched against those who presented scientific ideas. Figure 12, an extension of Table 5, shows a comparative analysis of identified alternative concepts that emerged out of the tiered test.

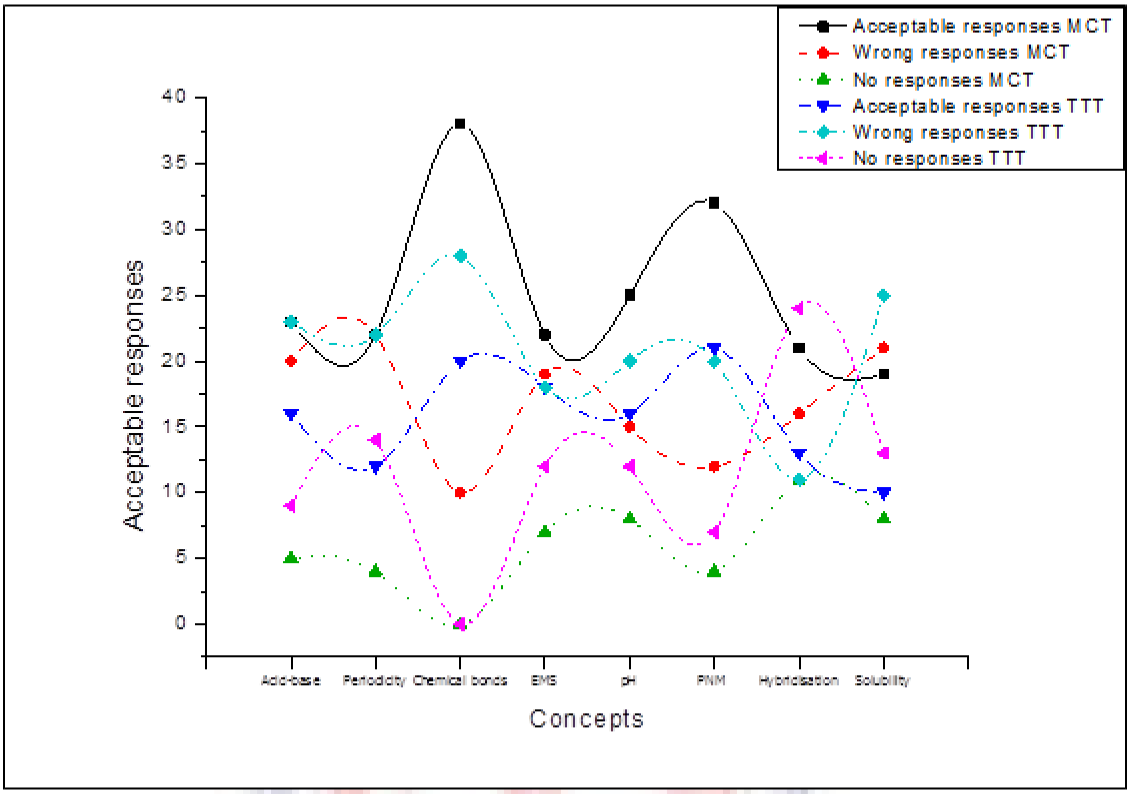


**Figure 12: Comparative analysis of trainees' correct, wrong and no-response performance in the MCT and TTT**

Major Finding 4

| |
|---|
| More trainees got the eight tested chemistry concepts wrong compared to those who got the concepts correct. Numbers of trainees with wrong responses for all eight topics were above 10%, with the highest wrong responses for chemical bonds. However, the highest misunderstood concepts were EMS, followed by acid-base and PNM. |

The trainees" understanding of the afore-stated chemistry concepts were again tested after the intervention period.

## Results from the post intervention phase

There were three activities in the post intervention phase, which were a post-intervention test, a student questionnaire and a semi-structured interview. However, only the post-intervention test results would partly support and answer RQ 1, of which part would be answered with the pre-intervention results. Here also, the post-intervention tests were assessed in two parts (as MCT and TTT) to ascertain concepts that the trainees had about the eight main concepts under study after the intervention.

## The post-intervention test

A post-intervention test comprising the same topics as for the pre-intervention test, but similar items, were given to the trainees at the end of the intervention period. Again, a diagnostic test adapted from Treagust"s (2006) two-tiered test model was used. In Treagust"s two-tiered test model, an examinee had to score all two tiers of a test item to gain one mark, if both parts were correct. If one part was wrong an examinee or learner got no score for the item in question. The same scoring procedure was adopted in the pre-intervention phase of this study. The adapted diagnostic concept test used in this study, comprised 100 objective tiered test items, based on the course for level 100 chemistry students. The diagnostic test comprised parts „a" and „b" or tiers one and two. Part „a" was 100 multiple choice items with four options while part „b" of the test comprised some short answer items which followed part „a" of the test items. A correct answer for each of the test items attracted a mark or a score of one. The total score on the test was 100 marks. The first tier or „a" (called the post-MCT) comprised factual multiple choice items. The trainees were supplied with answers from which they made a single choice. In the second tier or part „b" (called the post-TTT), the trainees had to either choose or make a reason to further substantiate the choice that they made in the first tier. In other instances, they had to complete reasoning statements to support choices made in the first tier. Each post-multiple choice test (post-MCT) item was followed by a reasoning question (post-TTT), which assessed trainees‟‟ in-depth understanding of scientific concepts. The second tier of the post-test was to find out if trainees truly understood the choices that they had made in their first tiers. This was also to confirm or refute their choices.

The raw scores of the post-test for the first tier only of the concept test, termed the post-intervention MCT, are presented in Table 6. Only part „a‟ of the post test was scored- independent of part „b‟. The second tier („b‟) was not scored in this case nor tied to one‟s success in the first tier.

**Table 6: Raw scores of trainees in a post-intervention multiple choice test (N=48)**

| Trainee No. | Post-test score | Trainee No. | Post-test score | Trainee No. | Post-test score | Trainee No. | Post-test score |
|---|---|---|---|---|---|---|---|
| 1 | 77 | 13 | 59 | 25 | 77 | 37 | 72 |
| 2 | 55 | 14 | 78 | 26 | 50 | 38 | 57 |
| 3 | 59 | 15 | 87 | 27 | 58 | 39 | 68 |
| 4 | 82 | 16 | 61 | 28 | 68 | 40 | 74 |
| 5 | 62 | 17 | 55 | 29 | 64 | 41 | 56 |
| 6 | 52 | 18 | 85 | **30** | **47** | 42 | 63 |
| 7 | 65 | 19 | 65 | 31 | 57 | 43 | 57 |
| 8 | 73 | 20 | 60 | 32 | 74 | 44 | 51 |
| 9 | 64 | 21 | 67 | 33 | 81 | 45 | 67 |
| 10 | 54 | 22 | 70 | 34 | 85 | 46 | 65 |
| 11 | 68 | **23** | **41** | 35 | 63 | 47 | 67 |
| 12 | 68 | 24 | 79 | 36 | 61 | 48 | 75 |

Mean Post-MCT= **65.3**

From Table 6, it is observed that 46 trainees out of 48 passed the post-concept test, with a pass mark at 50. Two trainees (shown in bold) obtained low marks in the test. These scores have not been presented graphically, as a comparative conceptual data will be presented later.

Major Finding 5

| |
|---|
| Majority of the trainees (46 out of 48) passed the test in the post-MCT with a mean score of 65.3%. |

A comparative analysis of the pre- and post-intervention MCT raw scores was carried out to find out if there were changes in mean scores and the numbers of trainees who passed in the post-test as compared to the pre-test. (Issues of interest are shown in bold). The comparative results are presented in Table 7.

**Table 7: A comparison of pre- and post-multiple choice test (N=48)**

| Trainee No. | Pre-score | Post-score | Trainee No. | Pre-score | Post-score | Trainee No. | Pre-score | Post-score | Trainee No. | Pre-score | Post-score |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 60 | 77 | 13 | 52 | 59 | 25 | 70 | 77 | 37 | 80 | 72 |
| 2 | 57 | 55 | 14 | 60 | 78 | 26 | 60 | 50 | 38 | 51 | 57 |
| 3 | 54 | 59 | 15 | 61 | 87 | 27 | 48 | 58 | 39 | 67 | 68 |
| 4 | 67 | 82 | 16 | 60 | 61 | 28 | 55 | 68 | 40 | 75 | 74 |
| 5 | 67 | 62 | **17** | **55** | **55** | 29 | 60 | 64 | 41 | 61 | 56 |
| 6 | 56 | 52 | 18 | 61 | 85 | **30** | **57** | **47** | 42 | 56 | 63 |
| 7 | 55 | 65 | 19 | 50 | 65 | **31** | **57** | **57** | **43** | **57** | **57** |
| 8 | 60 | 73 | 20 | 66 | 60 | 32 | 64 | 74 | 44 | 41 | 51 |
| 9 | 55 | 64 | 21 | 50 | 67 | 33 | 60 | 81 | 45 | 63 | 67 |
| **10** | **54** | **54** | 22 | 50 | 70 | 34 | 72 | 85 | 46 | 63 | 65 |
| 11 | 62 | 68 | **23** | **55** | **41** | 35 | 61 | 63 | 47 | 55 | 67 |
| 12 | 62 | 68 | 24 | 64 | 79 | 36 | 64 | 61 | 48 | 78 | 75 |

Mean Pre-MCT=59.8; Mean Post-MCT= 65.3

From Table 7, it is observed that 32 trainees improved upon their scores in the post-test. Four trainees had the same scores in both tests. Trainee numbers 10, 17, 31 and 43 made no progress in the post test. Twelve trainees (numbers in bold) scored lower marks in the post MCT- test. Two trainees did not pass the tests.

Major Finding 6

| |
|---|
| Majority of the trainees (32 out of 48) scored slightly higher marks on the post MCT than in the pre-MCT. |

For the purposes of clarity, trainees‟ performance scores in the multiple choice test has been compared with their post-multiple choice test (as percentages) of frequencies in Table 11.

**Table 8: A comparison of trainees' pre-and post-MCT scores: cognitive gains (N=48)**

| Scores | PREMCT (%) | POSTMCT (%) |
|---|---|---|
| 80+ | 2.1 | 10.4 |
| 70-79 | 8.3 | 20.8 |
| 60-69 | 45.8 | 37.5 |
| 50-59 | 39.6 | 27.1 |
| 40-49 | 4.2 | 4.2 |
| Below 40 | 0.0 | 0.0 |

When only one-part of the test item or first tier was considered, the mean test score was high, 60% and 65%, respectively for the pre-multiple choice and post multiple choice tests. In the pre- and post-MCT, the range of trainees‟ scores changed slightly at a set pass mark of 50. In both tests, a total of about 96% of the trainees obtained marks between 50 - 100%, while 4% of them failed. In the post-test, about 10.2% of the trainees was able to move to the „Above 80%‟ bracket as against 2% in the pre-test. Many more trainees, (20.8%), moved into the „70-79%‟ bracket, as against 8.3% in the pre-test.

These comparative data are presented graphically as Figure 13.

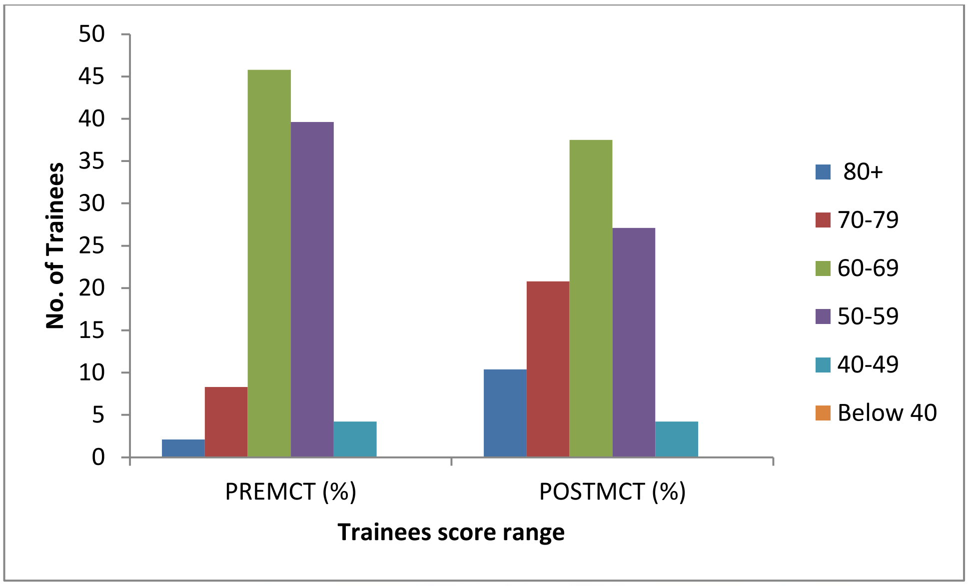


**Figure 13: Comparative analysis of trainees' conceptual understanding in the pre- and post-intervention tests**

Major Finding 7

| |
|---|
| A total of 96% of the trainees passed in both the pre-and post-MCT. There was no significant change. |

The raw scores of the post-intervention test for the combined first and second tiers of the concept test, termed the post-TTT, are presented in Table 9. Here, marks were awarded if only a trainee got both parts (first and second tiers) of an item correct. A correct answer in only one tier (part „a" or „b") merited no mark at all. That means that a score in either part was dependent in a score in another part of a same item. Scores of interest have been shown in bold.

**Table 9: Raw scores of trainees in a post-intervention-two tiered test (N=48)**

| Trainee No. | Post-test score | Trainee No. | Post-test score | Trainee No. | Post-test score | Trainee No. | Post-test score |
|---|---|---|---|---|---|---|---|
| 1 | 40 | 13 | 38 | 25 | 72 | 37 | 66 |
| 2 | 34 | **14** | **76** | 26 | 50 | 38 | 48 |
| 3 | 54 | 15 | 46 | 27 | 56 | 39 | 58 |
| 4 | 66 | 16 | 60 | 28 | 48 | **40** | **60** |
| 5 | 64 | 17 | 48 | 29 | 60 | 41 | 56 |
| 6 | 48 | 18 | 66 | 30 | 46 | 42 | 46 |
| 7 | 54 | 19 | 60 | 31 | 46 | 43 | 56 |
| 8 | 64 | 20 | 58 | 32 | 50 | 44 | 51 |
| 9 | 58 | 21 | 48 | 33 | 55 | 45 | 64 |
| 10 | 52 | 22 | 58 | 34 | 74 | 46 | 48 |
| 11 | 68 | 23 | 26 | 35 | 62 | 47 | 54 |
| **12** | **30** | 24 | 74 | 36 | 52 | 48 | 62 |

Mean post-TTT=54.8

From Table 9, it is observed that more than half the number of trainees who took the post two-tiered–concept test obtained 50 marks and above. These data will be later shown graphically in a comparative analysis with a pre-TTT data.

Major finding 8

| |
|---|
| Majority of the trainees (33 out of 48) passed the post-TTT with a mean score of 54.8%. |

It was noted from the trainees‟ post-intervention test results that more scientific responses were made by majority of them. A comparative analysis of trainees‟ performance in the pre- and post-two-tiered test was also carried out to find out if trainees improved on their marks in the two-tiered section of the concept test after their experience with the MCE. The comparative results are presented in Table 10. Scores of interest are shown in bold.

**Table 10: Analysis of trainees' output in the pre and post-two tiered tests (N=48)**

| Trainee No. | Pre-test | Post-test | Trainee No. | Pre-test | Post-test | Trainee No. | Pre-test | Post-test | Trainee No. | Pre-test | Post-test |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 36 | 40 | 13 | 26 | 38 | 25 | 40 | 72 | 37 | 44 | 66 |
| 2 | 30 | 34 | **14** | **30** | **76** | 26 | 32 | 50 | 38 | 32 | 48 |
| 3 | 38 | 54 | 15 | 34 | 46 | 27 | 28 | 56 | 39 | 48 | 58 |
| 4 | 40 | 66 | 16 | 48 | 60 | 28 | 28 | 48 | **40** | **56** | **60** |
| 5 | 42 | 64 | 17 | 28 | 48 | 29 | 38 | 60 | 41 | 36 | 56 |
| 6 | 36 | 48 | 18 | 38 | 66 | 30 | 34 | 46 | 42 | 38 | 46 |
| 7 | 26 | 54 | 19 | 28 | 60 | 31 | 30 | 46 | 43 | 40 | 56 |
| 8 | 34 | 64 | 20 | 36 | 58 | 32 | 38 | 50 | 44 | 24 | 51 |
| 9 | 28 | 58 | 21 | 26 | 48 | 33 | 26 | 55 | 45 | 30 | 64 |
| 10 | 30 | 52 | 22 | 28 | 58 | 34 | 44 | 74 | 46 | 34 | 48 |
| 11 | 38 | 68 | 23 | 20 | 26 | 35 | 32 | 62 | 47 | 26 | 54 |
| **12** | **36** | **30** | **24** | **34** | **74** | 36 | 36 | 52 | 48 | 38 | 62 |

Mean pre-TTT= **34.21**; Mean post TTT =**54.79**

From Table 10 it is observed that 47 (97.9%) of the trainees scored high marks above 50, while only one made six (6) marks less than he did in the pre-test. Two trainees (4.2%) made gains of 46 and 40 marks while nine (18.8%) made gains between 30 and 34 marks. Other gains made were between 4 and 28 marks. Scores of interest have been shown in bold. These upward gains indicated that generally trainees were now able to write correct answers and explain them with logical and scientific reasoning, thus they gained high scores on their post-intervention test. Their logical reasoning concepts which emerged from the tiered tests are presented as Appendices L and M.

Major Finding 9

| |
|---|
| Almost all the trainees (97.9%), apart from one, improved upon their scores in the second tier. |

Percentages of trainees" performance in a pre-two tiered test were compared with their post-two tiered test (as frequencies). This discriminatory, yet simple, analysis is presented in Table 11.

**Table 11: Comparison of pre- and post-two-tiered test: Cognitive gains (N=48)**:

| Scores | PRETTT (%) | POSTTTT (%) |
|---|---|---|
| Above 80 | 0 | 0 |
| 70-79 | 0 | 8.3 |
| 60-69 | 0 | 27.1 |
| 50-59 | 2.1 | 33.3 |
| 40-49 | 16.7 | 22.9 |
| Below 40 | 81.2 | 8.3 |

An analysis of scores presented in Table 11, shows that the majority of trainees performed poorly in the pre-TTT, but improved upon their post-test scores. Only 2.1% passed in the 50-59% range. In the pre-TTT, 97.9% of the scores fell below the 50% pass mark. However, in the post-TTT, only 31.2% of the trainees gained marks lower than 50%. This implies an increase of 66.7% correct responses or shift from the 0-49% range in the pre-TTT. In the post-TTT, 68.7% of the trainees obtained marks between 50 and 79; an improvement of 66.6%.

When both tiers of the test (TTT) are considered, the overall mean scores are lower, 34% and 55% respectively for the pre-two-tiered test and the post-two-tiered tests. Yet, the amount of gain made in the TTT is relatively higher than in the MCT test gains (64.99%). About 95% of trainees scored below 50% in the pre-TTT, yet in the post-TTT, only 32% of the trainees performed poorly as against about 95% failure in the pre-TTT who scored below 50% in the test. Table 11 is presented graphically as Figure 14.

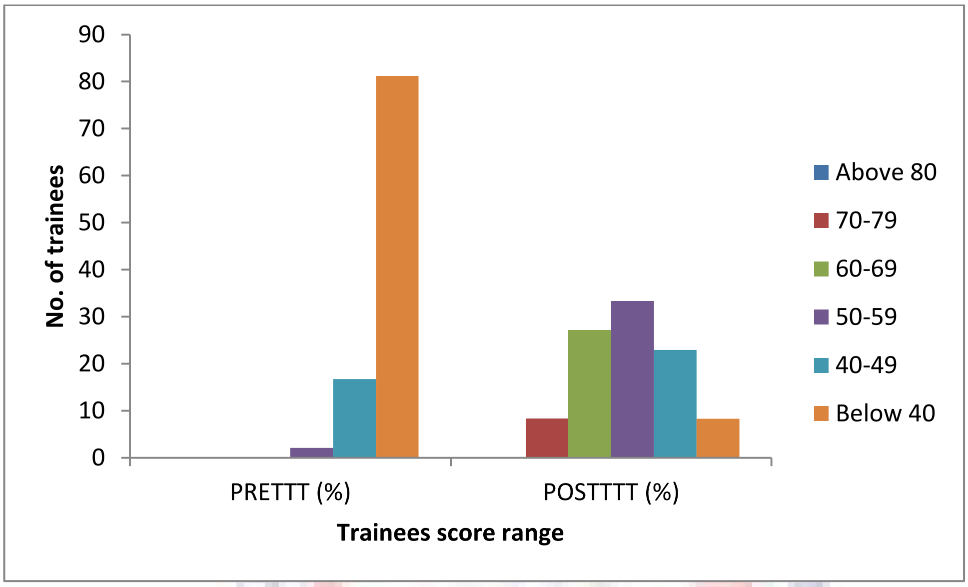


**Figure 14: A graphical representation of trainees' understanding of eight tested concepts**

Major Finding 10

| |
|---|
| About 66.6% of the trainees improved upon their scores in the TTT from the 0-49% bracket to 50% and above. |

Trainees‟ scores on the post-two-tiered test, with respect to the tested concepts which were answered correctly, were compared with scores gained in the pre-two-tiered test. The numbers of trainees who got the scientific concepts in the pre- and post-intervention test correct are presented in Table 12 as numbers and percentages. The results are arranged in order of increasing post-test improvement in scores.

**Table 2: Number of trainees' who made correct responses for tested concepts in the Pre-TTT and Post-TTT**

| Scientific concepts tested | Pre-TTT | Post–TTT | % increase |
|---|---|---|---|
| Hybridisation | 13 (27.1%) | 16 (33%) | 5.9 |
| Solubility | 10 (20.8%) | 17 (34%) | 13.2 |
| Acid-base strength and reactions | 16 (33.3%) | 25 (51%) | 17.7 |
| pH | 16 (33.3%) | 27 (56%) | 22.7 |
| Periodicity | 12 (25.0%) | 24 (49%) | 24.0 |
| Chemical bonds | 20 (41.7%) | 34 (70%) | 28.3 |
| Equations, mole, stoichiometry (EMS) | 18 (37.5%) | 32 (66%) | 28.5 |
| Particulate nature of matter (PNM) | 21 (43.7%) | 39 (81%) | 37.3 |

N = 48

From Table 12, it is observed that many trainees got most tested concepts correct in the post-intervention test with respect to the topics acid-base (51%), pH (56%), equations, mole and stoichiometry (66%), chemical bonds (70%), and particulate nature of matter (81%). Significant conceptual improvements were recorded in all the topics under study. The highest increase in correct response in the post-TTT was recorded for the Particulate Nature of Matter (PNM), while the least change was recorded for concepts associated with Hybridisation. Details of the said many improved conceptual changes and some specific responses are presented in Appendices K, L and M. However, a summary of the conceptual changes are shown graphically in Figure 15.

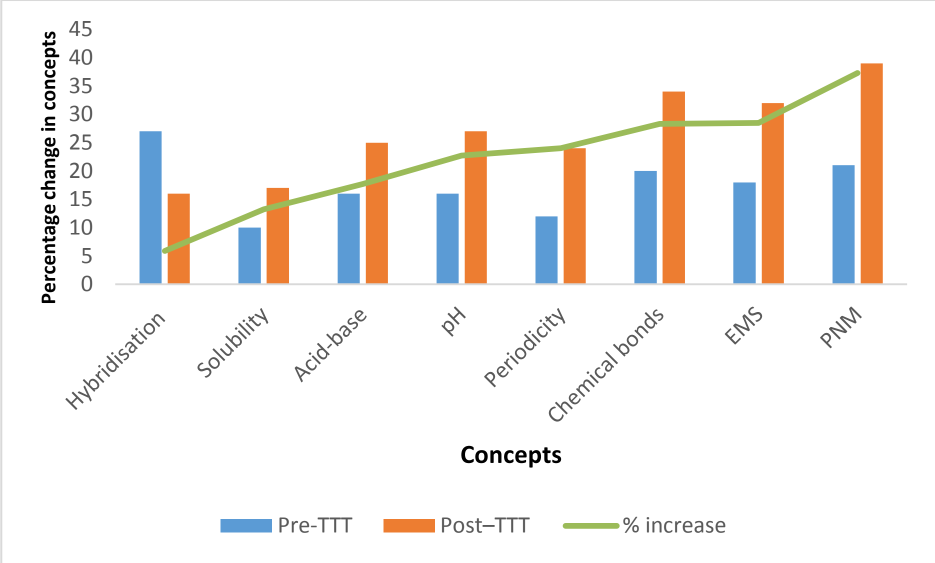


**Figure 15: Trend of improved conceptual change per topic**

Major Finding 11

| |
|---|
| There were increases in the number of trainees getting correct responses on all listed scientific concepts during the post-test. Less than half of the trainees passed in „hybridisation" and „solubility". |

A table of simple percentages of trainees" performances was used to find out how learners performed on a concept test through a change in TTT scores. Trainees" performance in a pre-multiple choice test has been compared with their post-multiple choice test (as percentages). In the same vein trainees" pre and post-two-tiered intervention test scores have also been compared. This discriminatory, yet simple analysis is presented in Table 13.

**Table 13a: Comparison of the pre- and post-multiple choice and two-tiered: Cognitive gains (N=48)**

| Scores (%) | PREMCT (%) | POSTMCT (%) | PRETTT (%) | POSTTTT (%) |
|---|---|---|---|---|
| Above 80 | 2.1 | 10.4 | 0.0 | 0.0 |
| 70-79 | 8.3 | 20.8 | 0.0 | 8.3 |
| 60-69 | 45.8 | 37.5 | 0.0 | 27.1 |
| 50-59 | 39.6 | 27.1 | 2.1 | 33.3 |
| 40-49 | 4.2 | 4.2 | 16.7 | 22.9 |
| Below 40 | 0.0 | 0.0 | 81.2 | 8.3 |
| Mean | 60 | 65 | 34 | 55 |

An analysis of scores presented in Table 13, shows that the majority of trainees performed poorly in the pre-intervention tests but improved upon their scores in the MCT and TTT post-intervention tests, though with a degree of difference. In the pre- and post-MCT, trainees‟ scores did not change at a set pass mark of above 50. In the TTT 97.9% of the scores fell below the 50% pass mark and obtained marks in the 0-49 percent range. However, in the post-TTT, only 31.2% of the trainees gained low marks from 0-49 percent. This implies an increase of 66.7% correct responses or shift from the 0-49% range in the TTT to 50% and above. In the MCT 95.8% of trainees scored between 50 marks and above in both the pre- and post-test. However in the TTT only 2.1% truly passed the TTT; for the same set of questions. These few trainees (2.1%) had marks between 50-59 in the TTT. In the post-TTT, 68.7% of the trainees obtained marks between 50 and 79; an improvement of 66.6%.

When only the MCT or first tier is considered, the mean test score is high 60% and 65%, respectively for the pre-multiple choice and post multiple choice tests. However, when both tiers (TTT) are considered, the overall mean scores are lower, 34% and 55% respectively for the pre two-tiered test and the post two-tiered tests. Yet, the amount of gain made in the TTT is relatively higher than in the MCT test gains (66.6%). About 98% of trainees scored below 50% in the TTT while with the MCT only 4% scored below 50%. In the post-TTT, now only 31.2% of the trainees performed poorly as against about 98% failure in the pre-TTT who scored below 50% in the test.

Major Finding 12a

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| About 66.6% of the trainees improved upon their scores in the TTT from the 0-49% bracket. |

In order to find out if trainees‟ performance in their understanding of concepts in the MCT and TTT had linkages, a paired samples correlation of trainees‟ changed scores was carried out. A correlation value of 0.5 to 1.0 means that there is an appreciable amount of correlation between variables. A value of 0.5 and below suggests that there is low or no correlation between variables in a study. In this study, paired sample correlation of the changed scores of trainees was carried out in order to get a more vivid picture of progress of trainees‟ performance in the TTT. The outcome is presented in Table 13b.

**Table 13b: Paired sample correlation**

| | Correlation | Significance | t | Sig 2-tailed |
|---|---|---|---|---|
| MCT & TTT changed scores | 0.327 | 0.023 | -9.033 | 0.000 |

Table 13b indicates that there is always a significant difference between scores awarded to students by means of the MCT and the TTT. There is a statistical significance difference (0.000) between the MCT and TTT gains or changed scores. There is little correlation between scores gained in the two tests. What this means is that there are significant differences between the Multiple Choice Test and Two Tiered Test changed scores for the trainees. The correlation value of 0.327 implies that gaining high marks in the MCT section does not really imply a high gain in marks in the TTT section of the test.

Major Finding 12b

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| There is low correlation (0.327) between the MCT and TTT pre- and post-test scores. Thus, the change in TTT outcomes is independent of MCT, and is highly significant. |

A gain in scores through the MCT does not imply a proportional gain in performance in a TTT. Trainees‟ performance, as observed in the two modes of scoring, are independent of each other.

**Results from the intervention phase**

There were three activities in the intervention phase, which were MCE-based practical activities, lesson delivery and observation with the aid of curriculum profiles. Data gathered from these activities were used to answer research questions 2 and 3.

**RQ 2: What skills would teacher trainees who are trained to use micro chemistry equipment for practical activities demonstrate in developing their practical activities?**

**MCE-based practical activities**

Micro chemistry equipment experimentation was used as an instrument to gather data for assessing the improvement of the chemistry teacher trainees‟ conceptual understanding of some basic inorganic topics. The trainees carried out 10 MCE concept-based practical activities which were on topics and concepts such as measurement of pH, quantitative analysis, qualitative analysis, stoichiometry and solubility. The results for eight out of these 10 practical activities have been presented in Table 14 in terms of observed behaviour, partially observed behaviour and non-observance of behaviour. The symbols +, ±, and – have been adopted (Mafumiko, 2008) to signify evidence or non-evidence of exhibition of some desired behaviours of the trainees. The positive sign (+) is used when a desired behaviour is observed or executed. When the behaviour is only partially observable, then the designed sign (±) is used. When a desired behaviour is not observed at all, the negative sign (-) is used. Two of the activities required the use of other standard equipment besides the MCE and so are not presented in Table 14.

**Table 14: Classroom implementation-observation results for eight MCE practical activities**

| Trainees" behaviour | Activities | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Relate prior knowledge to the day"s activity | - | - | - | + | ± | + | + | + |
| Contribute to pre-lab discussions & connect to the activity | - | + | ± | ± | ± | + | ± | + |
| Form groups & demonstrate acquisition of lab & process skill | ± | + | ± | + | + | ± | + | + |
| Trainee-trainee cooperation evident | ± | + | + | + | + | ± | + | + |
| Groups interact with each other and facilitator as expected | - | - | - | + | ± | + | + | + |
| Evidence of reading instructions with understanding | - | + | ± | + | + | + | + | + |
| Working with apparatus/materials for skills acquisition | + | + | ± | + | + | ± | + | + |
| Materials obtained and activities started with no fuss | - | ± | ± | + | + | + | + | + |
| Discussion of outcomes in small groups | + | + | ± | + | ± | + | + | + |
| Understanding and interest in the lab procedures and activities | + | + | ± | ± | + | + | + | + |
| Acquisition of concept and process skills | ± | + | ± | + | + | + | + | + |
| Work within the allotted time | - | ± | ± | + | + | + | + | + |
| Relate activities with theory | - | ± | ± | ± | + | + | + | + |
| Use concepts, terms and language with comprehension | - | ± | ± | + | + | + | + | + |
| Recap to confirm understanding of concept | ± | + | - | + | + | + | + | + |
| Relate newly learned concept in other situations to demonstrate permanent learning | + | + | ± | - | + | + | + | + |

-: behaviour not observed; ±: behaviour partially observed; +: behaviour observed

It is evident from Table 14 that the trainees had problems on their first encounter with the MCE approach in activity one, as the signs recorded were more of the negative (-) and partially exhibited /observed (±) signs. In activity 1, only three out of the 16 expected behaviours and demonstration of skills were observed. In activity 2, there were exhibition of 10 out of the 16 expected behaviours. However, in activity 3, for which the practical activity was on stoichiometry of acid-base reaction, one expected behaviour was observed, as against 12 partially observed behaviours. During the first three weeks of the study about half of the class could not relate well to the changes which came with the MCE approach. A detailed study of their practical workbook showed that the trainees were unable to distinguish between para-conceived terms such as „strong", „weak", „dilute" and „concentrated" which are associated with the description of acids and bases as well as other scientific terms and concepts. Other naïve conceptions were found in their understanding of periodic and group trends, the formation of chemical compounds and bonds, stoichiometry and associated concepts, the mole, solubility and hybridisation. In activities 4, 5, and 6, (as observed in Table 14) 12 out of the 16 behaviours expected of trainees were observed. However, as time went by, they were able to use the resources effectively to enhance their understanding of chemical concepts in inorganic chemistry. In activity 8, all 16 expected behaviours of the trainees were observed.

Major Finding 13

The expected skills (lab, process and concept) acquisition and observed behaviours were least in the first three weeks (for the topic chemical stoichiometry) but increased as trainees engaged in more MCE activities. They could not use concepts, terms and science language such as „dilute" and „weak" correctly.

The trainees were given two laboratory tests; one before their practical work sessions began, called the prelab, and then another after their practical work session, called the postlab for 10 sessions. The pre- and postlab tests were scored on a maximum of 5 marks each. There was a concept activity in between the pre- and postlab sessions which was also scored on a maximum of 10 marks. Each activity was therefore scored over a total of 20 marks. The results of all the 10 practical activities are presented as mean scores in Table 15.

**Table 15: Results of mean class scores for 10 MCE practical lessons**

| Lab | Activity | Prelab (5) | Postlab (5) | Concept (10) | Total score (20) |
|---|---|---|---|---|---|
| 1 | Acid-base indicators activity | 0 | 2 | 5 | 7 |
| 2 | Determining the concentration of an acid | 1 | 3 | 6 | 10 |
| 3 | Reaction of acids with NaOH (stoichiometry) | 1 | 3 | 7 | 11 |
| 4 | Reaction of Group 1 & 2 metals with water | 2 | 3 | 8 | 13 |
| 5 | Test for halides | 2 | 3 | 9 | 14 |
| 6 | Amount of substance in solution | 3 | 4 | 8 | 15 |
| 7 | Distinction between sulphates, carbonates | 3 | 4 | 10 | 17 |
| 8 | Test for ions in aqueous solutions | 4 | 4 | 9 | 17 |
| 9 | Solubility of group 2 metal sulphates | 3 | 5 | 10 | 18 |
| 10 | Stoichiometry of precipitation reactions | 4 | 5 | 10 | 19 |

From Table 15, it is observed that the trainees" mean scores on the prelab tests were mostly low while their postlab mean scores were relatively high. Mean class scores for the first four weeks were generally low. However, the trainees" performance in the conceptual development session of the practical activities increased steadily until activities 6 and 8 when there was a drop in concept mark for *amount of substance in solution* and *test for ions* from 9 to 8 and 10 to 9 respectively. Increase in mean scores in the conceptual development sessions is reflected in a commensurate increase in mean post-lab mean scores. For example, if a trainee developed a sound conceptual understanding of the action of water on groups 1, 2 and 3 metals in a progressive manner, then in their postlab tests they would be able to make a correct prediction of how subsequent elements along a period or in the other groups would behave in their reactions with water, based upon their developed conceptual understanding of periodic trends.

These observations, that trainees later showed improvement on their conceptual understanding, are corroborated by some of their responses. For example:

- *The MCE approach helped us to do our practical in small bits. This made us understand well than when the process was so long and boring in the past. The MCE experiment was helpful. I understood concepts about periodicity, stoichiometry and acid-base reactions better with time.*
- *If you performed the MCE activities properly they enabled you to answer the postlab and focus questions correctly through step-wise analysis. My group's scores increased steadily due to our increasing understanding of many concepts.*
- *We finished our work very quickly. We almost always understood what we did all the time and learned to make predictions which were often correct. We also understood why we often got our first questions (prelab) when activity ended.*
- *It was easy to interpret the MCE activity instructions so that you could design your experimental process yourself with little trouble and get the focus questions correct by the end of an activity.*

Major Finding 14

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| Trainees" performance on MCE activities increased steadily with time as their scores on conceptual development indicated. Their time, interpretive, predictive, deductive and critical thinking skills as well as conceptual understanding increased, especially with periodicity, acid-base reactions and stoichiometry. |

**Curriculum profile**

A curriculum implementation observation check list was used to determine the extent that trainees exhibited particular behaviours such as interaction with their colleagues and discussion of concepts with understanding during lessons. The results were analysed in terms of *observed behaviour* (+), *partially observed behaviour* (±) and *non-observance of behaviours* (-), Mafumiko (2008). The results are presented in Table 16.

**Table 16: Classroom implementation-observation results for five lessons**

| Trainee behaviour/Activity/ Response | Lessons | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 1.Relate prior knowledge to the day‟s lesson | + | - | + | + | + |
| 2. Contribute to diagnostic/ pre-lab discussions and connect them to the day‟s activity | - | + | ± | ± | + |
| 3. Form groups and demonstrate acquisition of lab and process skills | ± | + | + | + | + |
| 4.Trainees -trainee cooperation evident | ± | + | + | + | + |
| 5.Groups interact with each other and teacher as expected | - | - | ± | + | + |
| 6.Evidence of reading with understanding | - | + | + | + | + |
| 7.Evidence of skills acquisition with apparatus and materials during practical session | + | + | + | + | + |
| 8.Materials obtained and activities started with no fuss | ± | ± | - | + | + |
| 9.Discussion of outcomes in small groups | + | + | ± | ± | + |
| 10.Understanding and interest in the lab procedures and activities | + | + | + | + | + |
| 11.Demonstrate acquisition of concept skills through discussion | + | + | + | + | + |
| 12.Work within the allotted time | - | ± | + | + | + |
| 13.Relate activities to theory | ± | + | + | + | + |
| 14.Use the required concepts, scientific terms and language with comprehension | ± | ± | + | + | + |
| 15.Response to periodic recap to confirm understanding of concept | + | + | + | + | + |
| 16.Relate newly learned concept in other situations to demonstrate permanent learning | + | + | + | + | + |

+: observed behaviour; ±: expected action partially observed, - : indicator not observed or executed

Results from Table 8 revealed that trainees could not exhibit all the desired characteristics (skills) expected of them during their first lesson. However from the second lesson more of the desired behaviours expected from them to show that they understood what they were doing were observed. Trainees were able to relate prior knowledge to the day‟s lessons, collaborated actively with their colleagues, showed evidence of working with the MCE with understanding and related the activities with the chemistry theory under study. There were 11 positive indicator responses in the second lesson as compared to seven in the first lesson. The observed behaviour indicators increased consistently for subsequent lessons. These classroom observations corresponded with practical activity observations 1, 2, 5, 6, and 8 in Table 15.

Demonstrations for items 3, 7, 10, 11, 13, 14, 15 and 16, as observed in Table 16, were vastly positive.

Major Finding 15

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| Most trainees exhibited the desired learning skills during the lessons, within the allotted time, which was attributed to the interactive MCE learning environment. |

Items number 5, 6 and 7, from part A of the questionnaire, specifically sought answers for the question on how the trainees performed MCE activities with ease to demonstrate their conceptual understanding of some inorganic chemistry topics. The ease with which trainees perceived the use of the micro equipment was measured by means of a 5-point Likert scale, which ranged from values of 1-5 with interpretations which also ranged from „strongly disagree, disagree, not sure, agree and strongly agree" respectively. The responses „agree and strongly agree" were pooled together as favourable response under the heading „easy", while „not sure, disagree and strongly disagree" were pooled as unfavourable responses to the items analysed and labelled „Not easy". The results have been analysed and presented in terms of frequency and percent in Table 17.

**Table 17: Trainees' responses to the ease of use of MCE in demonstrating understanding**

| Ease of use of MCE | Easy (%) | Not easy (%) |
|---|---|---|
| 5 .The use of MCE made me feel like exploring my understanding of other topics, still using the MCE easily | 78 | 22 |
| 6. The use of MCE has given me confidence in planning other basic easy activities on my own | 78 | 22 |
| 7. It has exposed me to easier ways of conducting chemistry experiments | 82 | 18 |

From Table 17, about 78-82% of the trainees" indicated that they gained confidence in exploring their understanding of concepts with ease through the use of the MCE as responses in questionnaire items 5 and 7 particularly depict. This is corroborated by interview results in which some trainees said for example:

- *I liked to use the MCE. It's very useful. It was simple to use. I really liked it .It is easy to tell if someone understands what they are doing. For example, in executing the activity, one must be able to predict results, design appropriate presentation styles, observe/measure, record, calculate and go beyond all this make further predictions based on results of investigation.*
- *Lessons were better simply sequenced to make you work with ease than in the traditional approach*
- *We had the opportunity to do activities by themselves in other simpler ways other than was instructed on their worksheets without fear of explosions from wrong mixtures. This enabled us to acquire the necessary skills for understanding most of what we did.*
- *The setup was always simple and easy to work with*
- *It was fascinating and yet helps with concept understanding* as well
- *Very little time is spent when using the MCE as against the traditional approach because you quickly learn tricks (skills) to enable you work fast; with understanding*

These assertions made by the trainees corroborated their initial responses to questionnaire items on the usefulness and ease of use of the MCE.

Major Finding 16

Majority of the trainees (about 80%) were of the view that the MCE had exposed them to an easier way of interpreting and conducting practical activities with confidence on their own. The interactive nature of the MCE allowed for flexibility in the acquisition of learning skills.

The cooperative and collaborative nature of the MCE as well as how the MCE affected the trainees" relationship with their teacher was assessed through the questionnaire. The trainees" views on the interactive and collaborative nature of the MCE are presented as pooled responses from a 5-point Likert scale in terms of percent frequencies. Responses for the indicators „not sure, disagree and strongly disagree" were pooled as „negative responses", while „agree and strongly disagree" were pooled as „positive responses" for items. The pooled responses are presented as percentages in Table 18.

**Table 18: Interactive nature of MCE towards concept formation**

| The interactive nature of the MCE towards concept development | Positive responses (%) | Negative responses (%) |
|---|---|---|
| 1.The use of MCE was very helpful in my understanding of concepts | 76 | 24 |
| 2.The outlined practical activities and my understanding of concepts helped me to prepare better for other related topics | 78 | 22 |
| 3.The MCE has equipped me with skills and confidence in planning activities | 78 | 22 |
| 4.Collaboration enhanced my conceptual understanding of chemical principles | 80 | 20 |

From Table 18, majority of the trainees" responses were all positive in favour of the use of the micro equipment and how it facilitated their conceptual understanding. About 80% of the respondents said that classroom collaboration enhanced their conceptual understanding of chemical principles. All the other responses to the items in Table 18 were also positive (76-78%) in favour of the interactive nature of the MCE and its effect on their conceptual understanding. The negative responses were all low, ranging between 20-24%. This was corroborated by interview results in which some trainees said that:

- *There was better student-student as well as teacher-student cooperation which encouraged them to be more friendly with their teacher*
- *Lessons were better simply sequenced to enable you acquire skills to work with ease and confidence than in the traditional approach*
- *We were more actively involved in the lesson and so felt responsible for playing their own roles to understand the concepts*
- *Understanding some of the topics, like balancing of equations, helped me in understanding the mole concept which helped me in the topic on chemical stoichiometry.*

The interview responses corroborated the questionnaire responses which had earlier on been collated. Some of the corroborated phrases from the interview with respect to the questionnaire responses were:

- *The new approach suggested novel ideas and gave us confidence to attempt using other low-cost materials in our environment to perform activities – sometimes in groups*
- *One had to be truly a part of the class to achieve results, unlike in the traditional approach where there was a one-way kind of communication and the teacher knew it all and told it all – even during practical activities. We just followed instructions.*

- *There was no fear for breakages of glassware. It enabled concentration on the concepts to be studied rather than on manipulation and carefulness with equipment*

- *The predictions and challenge phase of this new approach in a way forces you to focus and re-focus on the main idea or concept in the activity being performed; Also it allows you a chance to compare your outcome with what you know already or what you have read.*

Interview item number 8 also probed further into the seemingly active nature of the intervention. It sought to find out if the MCE approach provided an active learning environment for the trainees. The question was: *Did you see the MCE approach as shifting focus from teaching to learning*? Trainees were of the view that the intervention stressed more on learning by engaging them intimately in the learning process without their teacher"s help. Some of their responses are presented in italics.

- *You only facilitated every time- kind of ..... (shy smile; no further response)*
- *We always had things to do; proper hands-on and so we had an active environment.*
- *This time we had to do most of the teaching and learning process or work ourselves. We enjoyed it though. We even acquired skills and designed MCE worksheets. Interesting exercise ....mmm.*
- *Yes, it was not like the old kind of teaching. Now you taught little and we worked more.*
- *Yes, the focus shifts from teaching to learning more now-with this approach. I think so because we do more work in this learning process. You do less talking and explaining and… Ok*

These responses inform what the trainees thought about the interactive and learner-centred nature of the MCE. Almost all their responses were positive in favour of the interactive nature of the MCE approach. They intimated that the MCE approach provided opportunities for them to acquire learning skills, so that they could work more actively than they did in the traditional approach.

Major Finding 17

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| Trainees intimated that the intervention was more interactive and learner-centred than the traditional approach. It equipped them with the necessary learning skills that enhanced their understanding of inorganic chemistry concepts. |

**RQ 3: What types of chemistry concepts would emerge out of the trainees' understanding of the MCE practical activities they perform?**

Many scientific concepts emerged through the MCE activities (Appendices L and M). The trainees‟ were able to predict and explain the product from the reaction between an acid and a base that salts would be formed. They found out from their MCE activities that seemingly neutral salts could be basic or acidic upon hydrolysis if they were conjugate acids of weak bases and conjugate bases of weak acids. They explained that a solution of $Na_2CO_3$ would be basic, with the equations below to explain their assertion.

i) $Na_2CO_3 \rightarrow 2Na^+ + CO_3^{2-}$

ii) $CO_3^{2-} + H_2O \rightarrow HCO_3^- + OH^-$

iii) $2Na^+ + HCO_3^- + OH^- \rightarrow NaHCO_3 + NaOH$

The overall equation then becomes:

$Na_2CO_3 + H_2O \rightarrow NaHCO_3 + NaOH$

From the above equation, the trainees were able to explain the hydrolysis event with good reasons after their MCE activities. They further added that NaOH was a strong base, while $HCO_3^-$ would be a weak base; thus, the stronger base would take precedence over the weaker base. That was an interesting analysis. It demonstrated the fact that the trainees were now reasoning and making choices analytically even if they were only partially correct.

A better scientific analysis, however, could have been as shown below:

i) $Na_2CO_3 \rightarrow 2Na^+ + CO_3^{2-}$

ii) $H_2O \rightleftharpoons OH^- + H^+$

iii) $2H^+ + CO_3^{2-} \rightleftharpoons H_2CO_3$ (Weak acid)

This leaves OH- in the solution which thus becomes alkaline.

Major Finding 18

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| Trainees noted that salts formed from acid-base reactions could hydrolyse to yield acidic or basic solutions depending on the strengths of the acid or basic part of the salt. |

Under the topic of periodicity, trainees were able to explain, more scientifically, the action of water on metals along periods and groups respectively. In an extension and reflective part of the activity, trainees were expected to predict and explain expected outcomes of the action of water and air on other elements based upon the evidence gathered from their activities with sodium, potassium, magnesium and aluminium. This enabled trainees to develop the ability to associate similar issues and distinguish dissimilar situations from similar ones. Thus, they were able to form scientific concepts from translation and transfer of ideas based upon prior evidence. The trainees learned to write and balance chemical equations of observed and expected reactions of metals and their salts with water. Other qualitative issues such as the solubility of compounds in water and other reagents were also discussed. After a few MCE activities they were able to express their understanding of the expected trends in statements such as:

- *I understand now that the reactivity of elements would increase down a group because valence electrons get further from the nucleus as sizes of atoms (radii) are get bigger (partial explanation). At first I thought the small elements would react swiftly.*
- *Along a period, beryllium would exhibit more covalent character than lithium but more ionic character than boron. I ascribe reasons for this not based on the duet or octet concept but on ease of loss of electrons based on positions of the elements on the periodic table and other factors. I do not force to use the octet rule. The activities also confirm my understanding.*

Details of the scientific concepts which emerged could be found as Appendices L and M.

Major Finding 19

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| Trainees were able to explain some periodic concepts scientifically without using the octet rule. |

The concepts of pH, buffers, acidity and basicity appeared to be difficult. pH was used in a „mechanical" or „technical" sense without a real grasp or understanding. The trainees assumed that one particular theory on acids or bases (the Bronsted-Lowry concept) could be used to explain all chemical behaviours and identities of acids and bases. The concept of Lewis acid could not be comprehended. They intimated that all salts which resulted from acid-base neutralisations reactions would be neutral, even upon hydrolysis. The trainees remarked that:

- *All acids are proton donors.*
- *Acids cannot be electron acceptors or ... they may donate electrons as they donate protons. pH of a base is 'bigger' than the pH of an acid.*
- *If the pH of a solution was high, then it meant that the solution was concentrated and so it would subsequently have a high molarity.*
- *A buffer resists change in pH. (The fact is correct but no tangible explanation could be given)*
- *Salts from acid-base neutralisations reactions hydrolyse to give neutral solutions.*

The last assertion on salts from acid-base neutralisation reactions could not be comprehended by the trainees until they observed through an activity that some salts which resulted from neutralisation reactions like the $AlCl_3$ salt could be acidic. The terms „big" and „bigger than" were used to describe dissociation constants such as pKb and pKa values indiscriminately. The word „bigger" was explained in many different but conceptually wrong ways. Some alternative concepts which were identified have been presented as Appendices I and J. These identified alternative concepts were discussed for the purposes of reinforcement of authentic concepts. Some of their responses after a few MCE activities on different concentrations of acids and bases were:

- *As pH gets lower on a scale, hydrogen ion concentration increases*
- *A Ka value of* $1.0 \times 10^{-3}$ *is higher than* $1.0 \times 10^{-13}$

- *Buffers will resist slight excesses of either a base or an acid because the conjugate base will react with the excess acid while a similar thing will happen when there is excess base in the system. (Equations were used to explain the above assertion by a trainee).*
- *If a solution also contained more $H^+$ ions, then it was a stronger acid than one which contained fewer ions.*

Other scientific concepts which emerged through trainees‟ engagement with the MCE have been presented as Appendices L and M.

Major Finding 20

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| Trainees had limited conceptions about the chemical characteristics, definitions and strengths of acids and bases. Their interpretation of Lewis acids, bases and buffers was misconstrued. |

Other MCE activities on the mole and chemical stoichiometry which trainees carried out after they learned to write and balance equations enabled them to improve on their definition of the mole and its associated concepts. For example, trainees had the general alternative idea that increasing an amount of one reactant in a chemical reaction, subsequently altered the mole ratios of the reacting species and affected concentration (Appendices I, J, K). That was a fallacy as there is no linkage between the three concepts: change in reactant volume or amount → change in mole ratio of reactants → change in concentration. Through several MCE activities on chemical stoichiometry and how to find out the concentrations of substances in acid-base reactions, trainees were able to understand and explain that increasing the volume or amount of one or all reacting species in a chemical reaction could affect concentration but not the ratio of reacting parts. Some of their unscientific answers to questions in the first three weeks of MCE activities were:

- *Increasing the volume of one of the reacting mixtures will affect the mole ratio*
- *The mole ratio for the equation will change when one compound is increased or reduced*
- *The limiting reagent is the species with the smallest coefficient in an equation or least mass.*

And then later more scientific responses were made after conducting MCE activities:

- *Changing the concentration or volume of one or both of the reacting components will have no effect on the mole ratio (ratios of coefficients) or subscripts.*
- *The nature of the individual reacting components and position on the periodic table determine the mole ratio and not how dilute or concentrated a chemical solution is*
- *A limiting reactant is the species with the least amount of substance (in moles)*

Major Finding 21

Trainees found that increasing the concentration or volume of a reaction mixture did not affect stoichiometric ratios as they previously thought. The limiting reactant was the stoichiometric species with the least amount of substance and not mass or mole ratio.

The topics treated in this study were interrelated and so conceptual knowledge gained was transferred easily by successful trainees, except with the concept of hybridisation. Activities on the topic-Particulate Nature of Matter (PNM) and Periodicity however, enabled some trainees to transfer knowledge so as to understand the abstract concept of Hybridisation. No direct MCE activities could be performed on hybridisation concepts. In the pre-test many trainees intimated that hybridisation was a mixing up of electrons in orbitals. They said that:

- *Orbitals must contain electrons before hybridisation occurs.*
- *It is possible to have ionic bonding in hybridisation.*

Later on in a post-test they intimated that

- *Hybridisation was a mixing up of native atoms and not electrons in an atom. (They explained in an interview, the concept that empty orbitals could hybridise).*
- *Electrons in hybridised orbitals as well as empty hybridised orbitals all bond up covalently and never ionically. Electrons cannot be transferred in hybridisation.*

Major Finding 22

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| Trainees could explain the term „hybridisation‟ as a mixing up of native atomic orbitals to give hybridised orbitals which bond covalently only with other species. Hence, ionic bonding was not possible in hybridisation. |

**Data gathered from lesson delivery**

Data were gathered in the course of each lesson delivery to assess trainees‟ conceptual progress with the intervention. Trainees were required to answer a short concept question for between 3-5 minutes at the beginning of a lesson. This unearthed some of the trainees‟ conceptual challenges. During the main lesson an observation checklist (Appendix B) was used by the Researcher, as a measure of the growth of trainees‟ understanding of basic inorganic concepts through the use of the MCE in practical work. The amount of time allowed between measures was short so as to increase the correlation value. In all, there were 10 MCE concept-based lessons (sample in Appendix F) which were supported by MCE concept-based practical activities in the classroom. Two of the activities were not fully supported by the MCE as we had to use other macro glassware equipment in addition. The additional equipment were the separation funnel and boiling tubes. Both the Researcher and the trainees used MCE curriculum materials (Appendices E, F, G and H) which were different from the traditional materials used in the University"s Department of Chemistry Education. The significance of the constructed MCE curriculum materials and how they supported trainees in their conceptual learning of inorganic chemistry principles may be seen in the exemplary materials that were constructed (Appendix B) for trainees. In the construction of the exemplary materials, the various skills (process, concept and manipulative) were considered and incorporated into the adapted materials. These were to be used as rubrics to assess the impact of the adapted RADMASTE materials on student learning. Eight out of the 10 lessons and activities which were taught solely with the MCE adapted curriculum materials were observed with an observation check-list. The other two activities were not wholly compatible with the sole use of the MCE. In all, the results of the observations seemed to be alike. Participants were able to interpret the requirements and suggestions on the curriculum sheets and implemented them accordingly. The observation checklist measured how far the MCE curriculum materials could support conceptual learning of chemistry concepts among trainees.

Classroom discourse was also recorded as an assessment of trainees" activities and progress during the administration of the microscale intervention and its accompanying adapted curriculum materials. Some benchmarks used during the classroom discourse were trainees" abilities to interpret scientific problems before the start of activities, suggestions on how activities could be performed and how they would present their Tables of results. Trainees" work materials were supplied and observations made to find out if they conformed to what the trainees had discussed and even more importantly, if they were interpreting the instructions in more mature and novel ways to arrive at scientific understanding of concepts.

The curriculum materials were expected to help trainees to read and prepare adequately ahead of each day"s lesson before class. This was because the course schedule indicated portions to be read for each day before class. Concept quizzes were very important in this study as they exposed any alternative concepts that trainees had before the start of each lesson. The curriculum materials and the concept quizzes enabled discussions that exposed trainees" alternate science concepts. Majority of the trainees showed marked improvements in the number of concepts they understood and came out with reasoned deductions on their practical work. The evidence of this improvement was demonstrated through the kind of answers that the trainees gave. They were able to explain concepts scientifically and made distinctive illustrations of terms such as that between the natures of solutions like acids and bases. For example, in distinguishing between the nature of acids or base they could draw schemes or figures similar to what is shown in Figure 16.

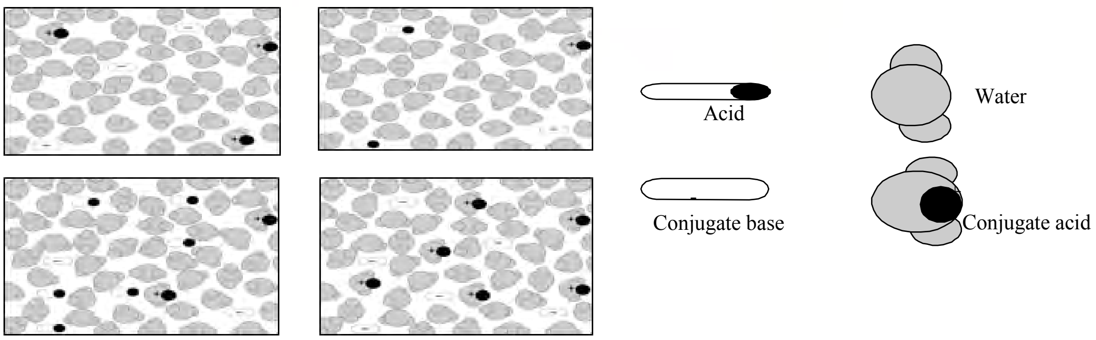


**Figure 16: An illustration of the nature of solutions**

A critical analysis of trainees‟ responses in the post-test MCT section of the concept test indicated fewer choices of alternative concepts than in the pre-MCT test. The details are shown in Appendix K. A summary of their output is shown in terms of the number of trainees who made correct responses in the pre-MCT test, as against the number that made correct responses in the post-MCT test. The detailed correct responses are presented in Appendix K. An overview of trainees‟ improved performance in their post-MCT responses in terms of numbers and percentages of correct responses in ascending order can be seen in Table 19.

**Table19: Percentage of numbers of trainees with correct responses for tested concepts in the Pre-MCT test versus Post-MCT responses (N=48)**

| Chemistry topics from which concepts were tested | Trainees with correct responses in pre-test | Trainees with correct responses in post-test | Trainees that showed improvement |
|---|---|---|---|
| PNM | 32 (66.7%) | 33 (68.0%) | 1 (2.1%) |
| Chemical bonds | 38 (79.2%) | 40 (82.0%) | 2 (4.2%) |
| Periodicity | 22 (45.8%) | 28 (59.0%) | 6 (12.5%) |
| Hybridisation | 21 (43.7%) | 27 (57.0%) | 6 (12.5%) |
| Solubility | 19 (39.6%) | 28 (59.0%) | 9 (18.8%) |
| Equations, mole, stoichiometry | 22 (45.8%) | 31 (64.0%) | 9 (18.8%) |
| pH | 25 (52.1%) | 37 (78.0%) | 12 (25.0%) |
| Acid-base strength & reactions | 23 (47.9%) | 37 (77.0%) | 14 (29.2%) |

From Table 19, it is observed that few trainees made improvement in the number of correct responses on the concepts for the topics tested in the MCT pre- and post-tests. The concepts which recorded the least improvements were the concepts on PNM and Chemical bonds. The pH concept showed 12 more correct responses in the post-intervention test than in the pre-intervention test. The highest improvements were made in the Acid-base concepts.

Major Finding 23

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| A considerable number of trainees made correct responses in the post-MCT, especially in the acid-base strengths and reactions, as well as the pH concept. |

A few scientific responses which indicated that trainees had made gains in conceptual cognition through the MCE approach were observed with topics such as the particulate nature of matter, chemical equations and stoichiometry and periodicity. Some of the scientific responses which indicated application and growth in knowledge were as follows:

**Particulate Nature of Matter (PNM):**

For an observed dissolution of copper sulphate crystals in water, when asked why the solution turned blue, they had responses such as: *the blue colour is a property of the particles in the copper sulphate. The water turned blue when the copper sulphate dissolved to give a solution. The copper sulphate particles mix with the water particles. As the copper sulphate particles spread throughout the solution the whole solution looks blue.*

Again when asked the question: Where did the copper sulphate go? Responses were:

*The copper sulphate is still part of the solution.*

They made similar correct responses with the sweet observations about sugar and salt solutions. *They attributed the characteristic taste of the respective solutions to the dissolved entities.*

Further questions involving the meanings of physical and chemical changes were also answered scientifically to show adequate conceptual understanding. In an MCE activity, a strip of magnesium metal was heated in oxygen till it burnt out. *Trainees made prior predictions that a new substance would be formed. They analysed their observations and deduced that chemical bonds as in the oxygen molecule were broken and new bonds formed in the metal oxide so the change was chemical. Some further said that different particles had resulted after the change. Others added that a great deal of energy was released in the reaction.*

**Chemical stoichiometry**

Some scientific or conceptual reasoning responses to stoichiometric questions were:

Q: Why is there a temperature change when hydrochloric acid and potassium hydroxide solutions are mixed?

A: *When they are mixed, the chemical reaction will involve the breaking of bonds in the reactants and formation of new bonds to produce the product. This results in either an increase or decrease in energy of the system in the form of temperature change.*

Q: Why would the temperature change differ when different volumes of HCl and KOH are used?

A: *Different amounts of products would be formed. Thus, the temperature changes would be different*

Q: What would be the mole ratios for the different ratios of reacting solutions? Explain.

A: *They would be the same ratio, 1:1. For every mole of HCl to fully react, only one mole of KOH is required.*

**Periodicity**

Q: Use your knowledge of the reactivity of the group 1 and 2 metals with water to explain why sodium, potassium and magnesium are not used in the test for hydrogen.

A: *The group one metals react vigorously with water and so is difficult to test for the hydrogen which will be produced. The nature of magnesium makes it react too slowly with water to produce sufficient hydrogen within a working period.*

Major Finding 24

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| Some scientific concepts exhibited by the trainees from the two-tiered test were the correct identification and use of substance, the implication of and application of stoichiometric terms and the periodic behaviour of elements with respect to periodic parameters. |

Item numbers 14 to 21 of the questionnaire sought to find out how the use of the MCE helped trainees to improve on their conceptual understanding. Trainees expressed their views on the use of the MCE as an intervention to enhance conceptual understanding by making choices on a Likert scale, which ranged between 1-5 points with the options „strongly disagree, disagree, not sure, agree and strongly agree respectively. The mean responses „agree and strongly agree" were pooled as positive responses, while the mean responses „not sure, disagree and strongly disagree" were collated as negative responses. The pooled responses presented in Table 20 as percentages.

**Table 20: MCE as an intervention to improve trainees' concept understanding of some inorganic chemistry topics**

| How the MCE helped to improve trainees‟ conceptual understanding | Positive responses (%) | Negative responses (%) |
|---|---|---|
| 1.The MCE helped me to develop a better conceptual understanding about Quantitative analysis | 84 | 16 |
| 2.The MCE helped me to gain a better conceptual understanding about Qualitative analysis | 85 | 15 |
| 3.The MCE helped me to understand more about the Mole concept | 83 | 17 |
| 4.The MCE helped me to understand more about the Stoichiometry concept | 84 | 16 |
| 5.The MCE helped me to have a better conceptual understanding of how to Balance chemical equations | 87 | 13 |
| 6.The MCE helped me to understand more Acid-base concepts and reactions | 87 | 13 |
| 7.The use of MCE helped me to understand the pH concept better | 86 | 14 |
| 8.The MCE helped me to understand how to write Net ionic equations | 83 | 17 |

Results from Table 20 indicated positive responses (above 80%) about the appropriateness of the MCE intervention towards the development of concepts such as the mole, stoichiometry, acid-base reactions, balancing of equations and qualitative analysis. Positive responses were high for the „balancing of chemical equations‟ and the „acid-base‟ concepts. As observed from Table 20, the trainees indicated (an average of 84.9% positive response) that the MCE intervention enhanced their conceptual understanding of some chemistry. This is corroborated by interview results in which some trainees said that the intervention provided a favourable condition for the development of sound chemistry concepts. The first interview item probed to find out about trainees‟ overall personal impressions about the MCE approach.

*What impressions do you have about the MCE lessons?*

Some of the teacher-trainees‟ responded as follows:

- *The MCE enhanced the way I understand concepts. I worked on all the projects and saw visible results which reinforced the ideas that I had. A few outcomes were not quite like what I expected or knew before the activity but the new* *results were very convincing and easy to accept as more logical and authentic than what I knew before.*

- *Yes. MCE broadened my conceptual understanding so well. Use of the miniature equipment exposed my misconcepts in a way I cannot explain. Simplicity does it, Madam.*
- *I particularly understood the concept of stoichiometry so well now with the MCE practicals. Mmmm, I saw that half the volume of tetraoxosulphate (VI) was required in neutralising a double volume of sodium hydroxide but equal volumes of sodium hydroxide and hydrochloric acid reacted because of their mole ratios. It was so practical and 'feeli feeli'.*
- *Doing the simple MCE activities and coming out with logical results makes me feel like a scientist in a medical lab (trainee laughs). I will do similar worksheets for my students because I see that the MCE can be used at all levels of education and at any place at all.*

Some other remarks made by the trainees suggested that authentic and accurate results, which outcome they could explain with understanding, were obtained in relatively shorter periods. These have been presented in Appendix M.

Major Finding 25

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| The MCE helped trainees to enhance their conceptual understanding of the scientific concepts under study, such as stoichiometry, in relatively shorter periods. It also exposed them to the versatile nature of the MCE. |

**RQ 4: What characteristics of the micro equipment activities would be suitable for developing a teaching manual?**

Of importance among the checklist were indications of how trainees interpreted and demonstrated Items 6, 7, 10, 11, 13, 15 and 16 on the observation schedule (Appendix B). A positive demonstration of Items 6, 7, 10, 11, 13, 15 and 16 meant that the trainees were using the MCE as a practical tool for self-directed learning and were showing a positive reaction towards the MCE. If they were able to relate their activities from the MCE approach with theory and did a good recollection to confirm their understanding of the concept after using the micro chemistry equipment, then it showed a gain in knowledge. More importantly, these gains indicated the usefulness of the designed materials and how they contributed to improving trainees‟ conceptual understanding.

**Results from the student questionnaire**

A questionnaire consisting of three parts (A, B, C) was used to diagnose trainees‟ understanding of basic chemistry concepts as well as their opinions on the use of the micro equipment. Section A of the Students‟ questionnaire assessed trainees‟ understanding, ease of use, and correct use of scientific concepts. Ability to understand and use scientific concepts correctly translates into being able to learn and apply the learned concepts in differing situations, especially during theory lessons. Items 1-8 on the questionnaire explored the trainees‟ views on their engagement with the MCE concerning its usefulness and usability. The response to each item on the questionnaire attracted a minimum rating of one and a maximum rating of 5 based upon a Likert scale rating of 1=strongly disagree, 2= disagree, 3= not sure, 4= agree and 5= strongly agree. The responses „agree and strongly agree‟ were pooled together as favourable responses under the heading „positive response‟, while „not sure, disagree and strongly disagree‟

were pooled as unfavourable responses to the items analysed and labelled „Negative response‟. The mean score for the responses to each item was translated into 100 points by multiplying each mean rating by 20. The items and responses are shown n Table 21.

**Table 21: Trainees' views on their engagement with the MCE**

| Trainees‟ views on the MCE approach | Positive responses | Negative responses |
|---|---|---|
| 1.Class activities were linked to theory topics discussed | 73 | 27 |
| 2.The MCE was very helpful in understanding concepts | 78 | 22 |
| 3.MCE activities and my understanding of concepts prepared me for other related topics | 77 | 23 |
| 4.The MCE enhanced the way I think critically | 78 | 22 |
| 5.The flexible use of MCE made me feel like exploring other topics, still using the MCE easily | 78 | 22 |
| 6.The MCE has equipped me with skills and confidence in planning other basic activities easily on my own | 77 | 23 |
| 7.It has exposed me to easier ways of conducting chemistry experiments | 82 | 18 |
| 8.It afforded me the needed opportunity to use materials and equipment | 86 | 14 |

Majority of the trainees responded to items on the questionnaire that the MCE activities linked theory to practice, allowed them to explore their ideas in a practical way and increased their confidence in performing activities with and for understanding. They added that the MCE approach exposed them to performing activities in easier ways as they had acquired the requisite skills. The responses to items ranged between 73 to 86% in favour of positive views about the MCE approach.

Major Finding 26

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| Majority of the trainees (73-86%) were of the view that the MCE was useful, skill-oriented, concept-oriented, robust and inherently interactive. |

**Trainees' likes and dislikes about the MCE as a conceptual change tool**

Section B of the trainees" questionnaire required the trainees to write what they liked or disliked about the MCE as a tool for concept development. It assessed the use of MCE for enhancing conceptual understanding of some chemistry topics. There were six open-ended items from which trainees" responses were put into themes. These themes bordered on how they liked or disliked the introduced MCE approach. Trainees" views are presented with respect to the themes in two broad categories- „like and dislike" in Table 22 as percentages. Interesting outcomes are presented in bold print.

**Table 22: Teacher trainees' likes and dislikes**

| Theme | Like % | Dislike % |
|---|---|---|
| Easily understandable materials | 78 | 28 |
| **Too many things to read** | **45** | **55** |
| **Helps to refute wrong ideas** | **87** | 13 |
| Confirms correct concepts quickly | 69 | 21 |
| Helps to build concepts from first principle | 81 | 19 |
| **MCE practical work gave faster and observable feedback** | **94** | 6 |
| **Interactive and collaborative** | **88** | 12 |
| Encourages critical thinking | 67 | 33 |
| **Sharpens observational and manipulative skills** | **89** | 11 |
| **Builds accuracy and precision** | **88** | 12 |
| More conceptual gains than in traditional lessons | 75 | 25 |
| Systematic presentation of lessons and activities | 69 | 31 |
| Longer discussion periods | 87 | 13 |
| **Pre-lab enables focus and recall on topic for the day. It prepares me on what to expect in a lesson** | **88** | 12 |
| Cannot perform all kinds of activities for all topics | 38 | 62 |
| **Stains propettes** | **51** | **49** |
| Increases confidence in ability to apply knowledge | 76 | 24 |
| Can be used in all levels of education | 72 | 26 |
| Shorter achievement time for results | 83 | 17 |

From Table 22, it is observed that more than 80% of the trainees liked the MCE because the pre-lab enabled them to focus on probable concepts in their preparation, sharpened their observational and manipulative skills, helped them to refute wrong ideas and was interactive. A total of 94% of the trainees particularly liked the MCE activities because it gave faster and observable feedback. Their overall general responses appeared to be in line with that of Tan et al., (2002) who proposed that the performance of practical activity and concept development go together. Majority of the trainees said that they learned how to construct their own knowledge so that learning became useful and memorable for them. The items which trainees responded negatively to were the fact that the MCE approach called for too much preparatory reading and the propettes got stained very quickly. They were also not happy with the fact that some activities could not be performed with the MCE. These findings from Table 22 are corroborated by interview results from interview questions 2 and 3 in which trainees said that they liked the MCE approach for reasons such as:

- *It was possible to set up many activities at the same time, like test tubes in a rack. Yet this time you could do many more activities than you would with real test tubes in a rack and yet compare all of one's many outcomes at the same time. It enabled us to work faster to achieve much in a short span of time.*
- *The MCE approach broadened my cognitive process. It exposed my misconcepts about terms such as concentration, weak acid, strong acid, dilute solution, stoichiometry, periodicity and others.*
- *I no longer have to sip chemicals through the pipette when the bulbs get sucked in.*
- *I didn't have to master any special skills to use the MCE. It was easy to use.*
- *Interaction between me and you increased dramatically. You interacted so freely with all of us. You went round to inspect and discuss every group's work. Working in pairs was also very helpful.*

The trainees" interview responses corroborated their responses to the questionnaire items in Table 22. They said that the MCE approach enabled them to work fast and achieved end results in shorter periods as compared to the traditional approach. They added that it was easy to use and did not require the specialisation of skills.

Major Finding 27

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| Trainees liked the MCE approach for the purposes of its fun, simplicity, accuracy, precision, inherent critical nature and shorter work periods. It enhanced their understanding of acids, bases, stoichiometry and periodicity. It could be used everywhere. |

Data on the usefulness of the micro chemistry equipment (MCE) in conducting chemistry practical activities was gathered through interviews with the trainees as well as through responses from close-ended items from Section C of the trainees‟ questionnaire. The items explored trainees‟ opinions on the usefulness of the MCE in their preparation of solutions, interpretation of theory into practice, and application of principles that they learned to other situations. Their responses were assessed and put into themes. The themes looked at how trainees prepared for each day‟s activities through pre-lab, how they conducted themselves and carried out practical activities, how useful the hints in their worksheets were and how useful post-lab discussions were towards their understanding and building of concepts. The means and significance of identified themes were worked out. A mean of 5.0 implied that the trainees found a particular theme very useful while a mean value below 2.50 (the mid-way value) meant that the desired theme was not useful. Data on the usefulness of the MCE is presented in Table 23. The points on the usefulness of selected themes were:

1 =Not helpful 2=little help 3=moderately helpful 4=helpful and 5= very helpful

**Table 23: Usefulness of the MCE and how it affected trainees' understanding**

| Usefulness of MCE for basic chemistry activities | 1 | 2 | 3 | 4 | 5 | Mean | 2-tail Sig |
|---|---|---|---|---|---|---|---|
| 1.Positive influence of Pre-lab discussions | 1 | 1 | 10 | 15 | 20 | 4.11 | .000 |
| 2.Influence of Post-lab discussions on understanding | 3 | 0 | 4 | 13 | 28 | 3.91 | .000 |
| 3.Analysis and explanation of experimental results | 1 | 4 | 4 | 18 | 20 | **4.34** | .000 |
| 4.Recall in Pre-lab | 0 | 3 | 7 | 18 | 20 | 4.11 | .000 |
| 5.Personal experience with MCE to get results | 2 | 1 | 3 | 10 | 32 | 3.98 | .000 |
| 6.Prediction of outcome before an activity | 1 | 1 | 8 | 26 | 12 | **4.36** | .000 |
| 7.Skills for preparation of work solutions | 5 | 5 | 14 | 09 | 10 | 3.75 | .000 |
| 8.Relating practice to theory/ Translating theory into practice | 2 | 2 | 13 | 12 | 19 | **4.46** | .000 |

All the means for the themes in Table 23 were above a mean value of 2.50. A statistical analysis of trainees‟ responses indicates that the pre- and post-lab discussions as well as the reflective and predictive part of their practical activities were useful for concept formation. They particularly found the pre-lab phase where they had to predict outcomes of activities to be performed quite useful (4.36) as well as the session where they had to relate practice to theory and vice versa (4.46). They also asserted that analysing and explaining the veracity of their experimental results through the use of the MCE was helpful (4.34 out of 5). All the assertions made by trainees on the questionnaire items were statistically significant. Results of the effect of pre-lab, post-lab, making predictions and doing activities to observe the outcomes significantly agree with trainees‟ assertion that the MCE affected their understanding of basic inorganic chemical concepts. From Table 23, we can see how the MCE significantly affected trainees‟ pre- and post-lab discussions, enabled them to analyse data, make useful predictions, prepare solutions and relate theory and practice. These findings from Table 23 are corroborated by interview results from items 6 and 7 in which some of the trainees answered that:

- *The MCE was useful as it enhanced the way I understand concepts. The visible results from projects I did reinforced ideas that I already had.*

- *Simple MCE activities enabled me to confirm some of my thoughts about some topics.*
- *The MCE approach broadened my cognitive process. It exposed my wrong ideas about terms like* ***concentration, dilute, strong*** *and* ***weak*** *solutions or acids and again helped me to form the correct understanding of many terms.*

The interview responses from trainees suggested that they found the MCE approach quite useful in improving their understanding of some basic inorganic topics.

Major Finding 28

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| The MCE was useful in relating practice and theory. It enabled the trainees to make predictions, explain their experimental results and analyse their outcomes. It also increased the formation of their process and concept skills |

In order to find out if the use of collaboration, through the MCE approach, was helpful for concept formation, trainees‟ responses to close-ended questions from Section A of the questionnaire were analysed. The ratings for the choices trainees had to make on a Likert scale were:

1 = strongly disagree 2= disagree 3 = not sure 4 = agree and 5 = strongly agree.

The mean responses for agree and strongly disagree were collated as positive responses while the mean responses for „not sure, disagree and strongly disagree‟ were collated as negative responses (all as percentages) for items on the importance of the MCE as a collaborative tool. The outcomes of the trainees‟ responses are presented in Table 24.

**Table 24: MCE as a collaborative/ cooperative tool for concept development**

| The collaborative /cooperative nature of the MCE towards concept development | Positive responses (%) | Negative responses (%) |
|---|---|---|
| The use of MCE increased student-student cooperation during lessons | 86 | 14 |
| The MCE increased student-teacher cooperation in the classroom | 82 | 18 |
| The MCE has given me confidence in planning other basic activities on my own | 78 | 22 |
| Cooperation in class enhanced my conceptual understanding of chemical principles | 80 | 20 |

All responses were vastly positive. Trainees were of the view that the MCE activities increased student-student cooperation in class which subsequently enhanced their conceptual understanding. More than 80% of the participants responded in favour of the MCE as having an inherent capacity to enable them to collaborate during practical activities. This is corroborated by interview results from interview item 5, to which trainees responded, for example:

- *Interactions between me and you increased dramatically. Mmm, it increased because now you go round the groups more often and we get the chance to question you with ease when the need arises*
- *Teacher gave more explanations to questions put forward and discussed questions which were related to the topic but not really a part of the day's activities. It enabled better understanding*
- *Thorough discussion of pre-lab with teacher in a relaxed manner*
- *Teacher ready to help all the time; allowed free discussions/ interactions between groups. It was good as one learned what one didn't know from a colleague.*

- *Interactions with other group members were quite helpful. It will be useful for large groups of students as it will keep all of them busy. It will be good for use in primary and even nursery schools.*

The responses made by trainees indicated that the MCE was a good teaching/learning tool which generated an active learning environment through collaboration.

Major Finding 29

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| The MCE, as a collaborative tool, enabled collaboration, in an active learning environment for concept development. The trainees intimated its usefulness for large classes. |

In the course of lessons, trainees analysed some of their worksheets (similar to Figure 16) and commented on the materials on them. Some of the comments that the trainees made in their interaction with the designed MCE curriculum materials were:

- *The curriculum materials (own interpretation) helped us to make use of our brains. We had to think critically and make good analysis and reasonable distinctions like the difference between the solution terms 'strong' and 'concentrated' and meaning of 'mole ratio'*
- *The worksheets makes write-up easy as we only fill in answers without repeating questions or long statements. We concentrated more on the topic and activity for the lab session.*
- *The type of activities in the MCE worksheets required critical thinking and thoughtfulness though it always seems like play work, with the little equipment.*

*Eventually I understood concepts on acid-base reactions, molecularity, stoichiometry, periodicity and solutions well.*

- *The MCE activities are structured in such a way that makes you think of other topics and connect them in a flexible, inexpensive way.*
- *Some of the worksheets are so simple that teachers can design their own special ones for topics that they teach. Simple ones can be designed for senior and even basic schools*

These statements made by some trainees indicated the quality of the MCE curriculum materials (worksheets, equipment and accompanying reading materials or study notes).

Major Finding 30

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| Some trainees indicated that MCE designed materials which could be used at all levels of education were structured to enable them to analyse their work materials critically, make reasoned deductions to understand concepts on acid-base reactions, molecularity, stoichiometry, periodicity and others with flexibility and at less cost. |

**Researcher's Logbook**

The Researcher‟s logbook was used to record incidental events which the observation schedule and the checklist did not cater for. The Researcher‟s logbook was used to keep a record of classroom activities and trainee behaviours which were not part of a schedule for the study but associated with the use of the micro chemistry approach. For example, difficulties that trainees‟ encountered but could not be indicated on the checklist as well as dramatic successes were noted in the logbook. Some of their important remarks in the course of practical activities were also noted in the logbook. The field notes contained in the logbook contributed to enrich the report of trainees‟

remarks, behaviours, and contributions in the research. The trainees" difficulties and other such experiences during the organization of their activities were recorded. Notes were also kept on the observed general response of participants attitudes. Some of the comments made by trainees that were captured in the logbook are:

- *Eih, how can we heat in these plastic containers …. Or they are like pyrex …?(One trainee throws hands up to show she does not know, followed by an outburst of laughter by others)*
- *It is so difficult to observe and distinguish between the colours of these halides. Perhaps we would have seen them better in the usual glassware? (The trainee stared at equipment with a puzzled look and long silence from onlookers). We will see how things turn out.*
- *Oh, now I can use coloured solutions to demonstrate strengths of acids and bases and their mole ratios in chemical reactions to other students or my colleagues. It is fun.*
- *We would have understood other topics better if we had done simple activities like these. I believe topics such as electrolysis and analytical chemistry can be taught like this.*
- *In the beginning I wondered if this pack of tiny equipment would be of any use to us. In fact they are easy to use. They are flexible and will be very useful for basic schools.*

Some trainees were of the view that the support materials had an inherent potential for the purposes for which they were used while others thought otherwise.

Major Finding 31

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| Some trainees were initially sceptical about the usability of the MCE but later indicated that it was robust, flexible, fun, and easy to perform activities with and would be useful for basic schools. |

**RQ 5: Would teaching through the MCE approach significantly change the way the selected inorganic chemistry topics are learned?**

In order to test whether the gains made in the post-MCT were statistically significant or not a t-test analysis was carried out since the means for the pre-intervention and post-intervention tests were different from each other. The paired samples result which indicates that the differences between the MCT pre- and post-test means are significant is shown in Table 12.

**Table 25: Paired samples t-test for MCT (N=48)**

| Post-test-pre-test | Mean | Standard deviation | Standard error mean | t | Df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|
| | 5.729 | 9.378 | 1.354 | 4.233 | 47 | .000 |

N=48

Results from Table 25 indicate that a significant gain was made in trainees‟ performance after they used the MCE at $t(47) = 4.233, p < 0.05$ with post-test scores higher than the pre-test scores at a 95% confidence interval of the difference. The MCT marks were about 9 marks away from each other. The difference between the pre-intervention test and post-intervention test was 5.7. This value tells how far away pre- and post-test mean scores were from each other. This also implies that the trainees‟ skills of answering concept questions have improved significantly and would give more scientific answers than before (Lemke, 2007). Performance gains made through the micro chemistry equipment (MCE) intervention are statistically significant as indicated in the analysis of multiple choice test (MCT) post-test scores in Table 25.

Major Finding 32

The overall progress made from pre- to post-test scores was statistically significant. Thus the use the MCE intervention increased the trainees‟ post-test scores.

In order to get an overview on the TTT and to determine whether there was a significant change in the numbers getting the scientific concepts correct or not, a two-tailed test was carried out. A two-tailed test measures the capacity or performance before and after an activity. In this study, the two-tailed test was used to find out if there were statistical differences in the marks that trainees obtained in the two-tiered test. The minimum and maximum marks gained by trainees in the pre-intervention and post-intervention test as well as significant changes in the test are shown in Table 26.

**Table 26: Descriptive statistics for the Two-Tiered Test (N=48)**

| | **Minimum** | **Maximum** | **Mean** | **Sig (2-tailed)** |
|---|---|---|---|---|
| Two-tiered pre-test scores | 20.00 | 56.00 | 34.2083 | 0.000 |
| Two-tiered post-test score | 26.00 | 76.00 | 54.7917 | 0.000 |
| Changed scores (gains) in the Two-tiered test | -6.00 | 46.00 | 20.5833 | 0.000 |

The mean scores in the pre-TTT moved from 34.2 to 54.8, indicating an upward change of 20.6 units

Major Finding 33

A significant upward gain of 20.6 units was made by trainees in the post-TTT.

In order to test whether the gain in the TTT was significant or not, paired sample t-test analysis of the trainees pre- and post-TTT was carried out. This test shows the difference between the pre- and post-test mean scores at a 95% confidence level. The outcome for the analysis is shown in Table 27.

**Table 27: Paired samples t-test for the two-tiered test**

| Post-test-pre-test | Mean | Standard deviation | t | df | Sig. (2-taiked) |
|---|---|---|---|---|---|
| | 20.58 | 9.6 | 13.835 | 47 | .000 |

Results from Table 27 indicate that a significant gain was made in trainees" performance after they used the MCE at $t(47) = 13.84$, $p < 0.005$ with post-test scores higher than the pre-test scores at a 95% confidence interval of the difference. The 48 participants had an average difference from pre-test to post-test of 20.58. That is, the difference between the mean pre-TTT and the mean post-TTT is 20.58, which indicates statistically gains in the TTT. Gains made through the MCE intervention are statistically significant as indicated in the analysis of TTT post-intervention test gains (0.000).

Major Finding 34

The overall progress made from pre- to post-TTT gains is statistically significant. On the average, scores moved up by 20.6 marks.

**Table 28: Comparative analysis of trainees' performance with the use of the MCE**

| | Min. scores | Max. score | Mean | Skew | F | Sig |
|---|---|---|---|---|---|---|
| MCT Changed scores | -10 | 26 | 6.17 | .070 | 0.566 | 0.907 |
| TTT Changed scores | -6 | 46 | 20.50 | -.097 | 3.652 | 0.001 |

There isn‟t much change in the MCT scores as compared to the TTT changed scores. The significant change of 0.001 for the TTT shows that significant gains were made in trainees‟ comprehension and cognition with respect to their ability to reason scientifically and choose answers after using the MCE, which was the only introduced variable in the inorganic chemistry lessons.

Major Finding 35

The MCE made a significant change in trainees‟ understanding of some inorganic chemistry topics.

## Summary of Findings

There were 35 Findings which are presented below.

1. Majority of the trainees (46 out of 48) passed the test in the MCT section.
2. Majority of the trainees did not show conceptual understanding of most basic chemistry concepts, especially, solubility and hybridisation. They appeared to have high scores in only three concepts out of eight; namely, chemical bonds, pH and PNM
3. Almost all the trainees (97.9%) performed poorly on the conceptual reasoning part of the diagnostic test.

4. More trainees got the eight tested chemistry concepts wrong in the TTT as compared to those who got the concepts correct. Numbers of trainees with wrong responses for all eight topics were above 10%, with the highest wrong responses (52%) for chemical bonds. However, the highest misunderstood concepts were equations, mole and stoichiometry, followed by acid-base and PNM.

5. Majority of the trainees (32 out of 48) passed the test in the post-MCT with a mean score of 65.3%.

6. Majority of the trainees (32 out of 48) scored higher marks on the post-MCT than in the pre-MCT.

7. A total of about 96% of the trainees passed in both the pre-and post-MCT. There was, however, little improvement or virtually no difference in trainees‟ scores.

8. Majority of the trainees (33 out of 48) passed the post-TTT with a mean score of 54.8%.

9. Almost all the trainees (97.9%) apart from one improved upon their scores in the second tier of the post-test.

10. About 66.6% of the trainees improved upon their scores in the TTT from the 0-49% bracket to 50% and above.

11. There were increases in the number of trainees getting correct responses on all listed scientific concepts during the post-test.

12. About 66.6% of the trainees improved upon their scores in the TTT from the 0-49% bracket. There is low correlation (0.327) between the MCT and TTT pre-

and post-test scores. Thus, the change in TTT is independent and highly significant.

13. The expected skills (lab, process and concept) acquisition and observed behaviours was least in week 3 (for the topic chemical stoichiometry) but increased as trainees engaged in more MCE activities. They could not use concepts, terms and science language such as „dilute" and „weak" correctly. Trainees" performance on MCE activities increased steadily with time as their scores on conceptual development increased.

14. The MCE designed materials enabled trainees to analyse their work sheets and materials critically so as to come out with reasoned deductions. Their performance on MCE activities increased steadily with time as scores on conceptual development indicated. Their interpretive, predictive, critical thinking skills and conceptual understanding increased especially with periodicity, acid-base reactions and stoichiometry.

15. Most trainees exhibited the desired learning skills during the lessons, within the allotted time, which was attributed to the interactive MCE learning environment.

16. Majority of the trainees (about 80%) were of the view that the MCE had exposed them to an easier way of interpreting and conducting practical activities such as identification of ions with confidence on their own through the acquisition of lab, concept and process skills.

17. Trainees intimated that the intervention was more learner-centred than the traditional approach such that it engaged them actively in activities and enhanced their understanding of inorganic chemistry concepts.

18. Trainees noted that salts formed from acid-base reactions could hydrolyse to yield acidic or basic solutions depending on the strengths of the acid or basic part of the salt.

19. Trainees were able to explain some periodic concepts scientifically without the octet rule.

20. Trainees had limited conceptions about the chemical characteristics, definitions and strengths of acids and bases. Their interpretation of Lewis acid, Lewis bases, and buffers were misconstrued.

21. Trainees found that increasing the concentration or volume of a reaction mixture did not affect the stoichiometric ratios as they previously thought. The limiting reactant was the stoichiometric species with the least amount of substance.

22. Hybridisation is a mixing up of native atomic orbitals to give hybridised orbitals which bond covalently only with other species. Ionic bonding is not possible in hybridisation.

23. A considerable number of trainees made correct responses in the post-MCT, especially in the acid-base strengths and reactions as well as the pH concept.

24. Some scientific concepts exhibited by the trainees from the two-tiered test were the correct identification and use of substance, the implication of and application of stoichiometric terms and the periodic behaviour of elements with respect to periodic parameters.

25. The MCE helped trainees to enhance their conceptual understanding of the scientific concepts under study, such as stoichiometry. It also enabled trainees to make logical scientific deductions about concepts taught.

26. Majority of the trainees (73-86%) were of the view that the MCE was useful.

27. Trainees liked the MCE approach for the purposes of its simplicity, accuracy, precision, inherent critical nature and relatively shorter work periods.

28. The MCE was useful relating practice and theory. It enabled the trainees to make predictions, explain their experimental results and analyse their outcomes. It also increased their process and concept skills

29. The MCE, as a collaborative tool, enabled collaboration, in an active learning environment for concept development. The trainees intimated its usefulness for large classes and lower primary.

30. The MCE designed materials which can be used at *all levels* of education were structured to enable trainees to analyse their work sheets and materials critically and make reasoned deductions to understand concepts on acid-base reactions, molecularity, stoichiometry, periodicity and others with flexibility at a cheap cost.

31. Some trainees were initially sceptical about the usability of the MCE but later indicated that it was simple, robust, flexible, fun, and easy to perform activities with and would be useful for basic schools.

32. The overall progress made from the pre-intervention test to post-intervention test scores was statistically significant. Thus the use the MCE intervention increased the trainees‟ post-test scores.

33. A significant upward gain of 20.6 units was made by trainees in the post-TTT.

34. The overall progress made from pre- to post-TTT gains is statistically significant. On the average, scores moved up by 20.58 marks.

35. The MCE, greatly enhanced trainees comprehension of some selected inorganic chemistry topics.

Major findings indicate that the MCE approach was effective in providing positive learning experiences for the trainees. It enhanced their understanding of topics such as periodicity, molecularity, stoichiometry, acid-base concepts and the mole concept. Results gathered from the interview corroborated the questionnaire data and showed that trainees liked the MCE approach as it was simple, provided an active learning environment and promoted active learning. Trainees did not only enjoy the lessons; they were also encouraged to learn more about many basic inorganic chemistry concepts. The MCE approach availed a platform for new ideas to be considered more seriously through reflection.

**Summary of Chapter Four**

Data gathered from the study through the use of concept tests, classroom activities, observation schedules, questionnaires and interviews were presented in this chapter. Major findings from the use of various instruments showed that trainees engaged with the MCE in such a manner that vast improvements in conceptual understanding were achieved. The findings indicate that the trainees found the MCE highly interactive, and having the potential to unearth their alternative conceptions; thus, helping them to build a sounder understanding of scientific concepts. This latter assertion was reflected in the quality responses provided by the trainees as well as their improved performance in a post-test.

# CHAPTER FIVE

## DISCUSSIONS

### Overview

The Major Findings of the MCE approach and its impact on concept development in basic inorganic chemistry are discussed in line with the research questions formulated in Chapter Two. These main findings are supported by notes from the Appendices. The teacher trainees were able to acquire and demonstrate 16 learning skills while the two-tiered test was able to unearth many of their alternative conceptions about basic inorganic topics. Some of these alternative conceptions were identified to be preconceived notions, non-scientific beliefs, conceptual misunderstandings, vernacular misunderstandings and factual misconceptions, as identified by Gooding and Metz (2011). The trainees in this study were also able to identify 18 attributes of the MCE as basis for developing MCE-based teaching manuals. The trainees" engagement in MCE practical activities and acquired learning skills helped them to correct most of their identified alternative concepts. The concept of hybridisation in compounds was, however, the least well understood topic through the MCE approach.

### The MCE study

The study was initiated to explore the possible use of simple highly interactive forms of practical work to support an active learning environment with low demands on equipment and consumables. This new approach was to help teachers to be able to implement practical work in chemistry with very little fuss and to move away from the cook-book methods. It was also to help teachers and students implement practical activities without the need for a traditional well equipped laboratory. In addition, it was to promote active participation and learning with understanding in tertiary teaching institutions.

The five research questions addressed in the study were:

1. *What types of concepts in inorganic chemistry would trainees come out with on a two-tiered test?*
2. *What skills would teacher-trainees who are trained to use Micro Chemistry Equipment for practical activities demonstrate in developing their practical activities?*
3. *What types of chemistry concepts would emerge out of the trainees' understanding of the practical activities they perform?*
4. *What characteristics of the micro equipment experiments would be suitable for developing a teaching manual?*
5. *Would teaching through the MCE approach significantly change the way that some selected inorganic chemistry topics are learned?*

In order to answer these questions, the study adopted a three-phase study. The first phase of the study consisted of activities such as front end analysis, a developmental stage where MCE teaching and learning materials were designed, developed and finalised for implementation. The front-end analysis consisted of context analysis, which is actually a situational analysis with respect to the learning of chemical principles, which led to a review of related literature. The essence of the context analysis was to gain an insight into the existing practices of chemistry education in Ghana, especially the universities and specifically, how practical activities impacted on students" cognition and concept formation in UEW. It also enabled the review of the practical work in UEW with a particular focus on some developing countries in sub-Saharan Africa and how they had solved their own lack of science resources and the formation of authentic science concepts by their learners.

Reviewed literature revealed the importance of finding out students" prior conceptions about topics before teaching or improving on them if the need be. Thus, a best possible way, the two-tiered diagnostic test (Tan, Goh, Chia, & Treagust, 2002; Treagust 2006), was developed to diagnose students" prior conceptual level and subsequent needs.

In phase two of the study the developed curriculum materials were used in the classroom to enable teacher trainees identify any possible alternative conceptions that they had, build sounder concepts and learn the necessary manipulative, process and concept skills to develop MCE practical activities. MCE-based lessons were used while the trainees were observed for various skills development and acquisition. Data from classroom activities and exercises were analysed for trainees" conceptual progression.

Phase three of the study assessed the impact of the MCE intervention on the research sample through the use of research instruments such as the post-test, questionnaire, and semi-structured interviews. Data gathered through these instruments were analysed in order to get an impression of how trainees fared in their engagement with the MCE. The outcome of the Major Findings (MF) from the research is discussed in line with the research questions.

**Research Question 1**

**What types of concepts in inorganic chemistry would trainees come out with on the two-tiered test?**

The answer to research question three was found in Major Findings MF 6, MF 10, MF 11, MF 18, MF 19, MF 20, MF 21, MF 22 and MF 24. This question explored the effectiveness of a developed 2-tiered diagnostic instrument in unearthing teacher trainees‟ alternative and scientific conceptions in basic inorganic chemistry. The MCT was not able to unearth as many of the trainees‟ alternative concepts as did the TTT, especially in the pre-test. Majority of the trainees demonstrated inadequate conceptual understanding of most basic concepts. They „appeared‟ to perform well in the first tier (part one) which required mere recall of facts without proof of understanding. Nevertheless, some scientific concepts also emerged. The following alternative concepts emerged from the pre-test:

1. All salts which result from acid-base reactions are neutral salts and so form neutral solutions with water (MF 18)
2. Acid strength is based on the concentration of an acid solution. The same holds true for a base (MF 20)
3. A Lewis acid donates protons or forms hydronium ions in solution (MF 20)
4. A buffer solution is in-between acidity and basicity but really none of each - neutral, kind of (MF 20)
5. Electron transfer (ionic bonding) is characteristic of hybrid orbitals (MF 22)
6. The octet rule can be used to explain why solubility of sulphates of group 2 elements increases with increasing atomic number of the element. It is because ionic character increases with ease of electron loss as is observed down a group. Thus solubility will increase (MF 21, MF 24)

7. pH determines acid strength (MF 20)
8. Identification and use of substance -ionic bonds and ionic compounds are stronger and harder than covalent bonds and molecular compounds (MF 24).
9. A positive ion can only be attracted to one negative ion (MF 21, MF 24)
10. Covalency can exist in ionic compounds. (MF 24)
11. There are ions in the ionic compound, sugar (MF 21, MF 24)

The trainees in this study exhibited more erroneous conceptions in the TTT than they did in the MCT. For example, they had preconceived notions such as „all solids are hard and have definite shapes like sugar‟. They could not understand that sulphur (powder) was solid, as it had no fixed (rectangular or circular) shape. Again, because in our everyday lives as Ghanaians, we use the words „dissolve‟ and „melt‟ interchangeably in our local dialects, the trainees had difficulties distinguishing between the terms. When sugar dissolves in water or beverage, we say, the sugar has „melted‟, in our local dialect. There are no words to distinguish „melt‟ and „dissolve‟. This type of conceptual conflict encountered in learners‟ understanding of concepts, termed vernacular misconceptions‟ were quite common. The trainees showed a lot of non-scientific beliefs (acids can burn all things), conceptual misunderstandings (weak solutions are the same as dilute solutions) and factual misconceptions (all salts are formed from the reaction between acids and bases and so they are all neutral).

In the post-test, majority of the trainees showed adequate conceptual understanding by providing more correct reasons for their factual choices in the first tier of each item. Some scientific concepts which emerged from the post-tiered concept test were:

1. Some hydrolysed salts from neutralisation reactions could be acidic, neutral or basic, depending on the original acid and base solutions which reacted to produce the hydrolysed salt. (MF 18)

2. Acid strength depends on the degree of dissociation of a molecule of acid to give hydrated hydrogen ions in solution, while concentration means the amount of solute dissolved in a solvent (MF 23, MF 24).
3. The same explanation on degree of dissociation of a base into its hydrated OH ions was given as the determinant for the strength of a base and the amount of OH ions per solution as the concentration of a base (MF 23, MF 24).
4. Lewis acids and bases behave like electrophiles and nucleophiles respectively. Their acidity and basicity are not based on aqueous solutions as observed in the Arrhenius concept or donate and accept protons as in the Bronsted-Lowry theory (MF 20).
5. Increasing the concentration or volume of a reaction mixture has no effect on stoichiometric ratios (MF 21, 24).
6. The limiting reactant in a chemical reaction is the species with the least amount of substance and not mass (MF 21).
7. Hybrid orbitals bond covalently by sharing electrons (MF 22)
8. The reactivity of these halogens decreases down the group. Since the reactivity decreases down Group 7, $F_2$ (g) is predicted to be the most reactive of all the halogens because it is at the top of the group. The octet rule cannot be used to explain this observation (MF 19, MF 24).
9. A negative ion can be bonded to any neighbouring positive ion, if it is close enough (MF 24)

The number of trainees who passed in the MCT (which is the objective or first part or „a‟) did not change after the intervention (MF 7 and 23). This implies that the objective section of the test was not discriminatory enough. It was unable to unearth the real alternative conceptions that the trainees had. According to Treagust (2006) and

Tan, Goh, Chia and Treagust (2002) single tiered tests do not have as inherent a capacity to unearth student‟s true misconceptions as the 2-tiered test. Their observations were based on findings from studies that they conducted in Malaysia and Australia. They made many more correct responses in the post 2-tiered test, which is an indication of improvement in their conceptual understanding. Majority of the trainees however passed the reasoning part of the test (TTT) after the intervention and improved on their conceptual responses by about 63% except one trainee (MF 9). For example, trainees could explain that increasing the concentration of one or both reacting species did not affect the mole ratio of the species because the same proportional amounts would react at any given time regardless their physical quantities. They could logically deduce the correct mole ratios for chemical reactions such as the reaction between tetraoxosulphate (VI) acid and sodium hydroxide as 2:1 and not the usual 1:1 mole ratio that they were used to and yet could not explain the reason for its use. This implied that majority of the trainees were able to make more informed scientific decisions after the intervention. In 2-tiered test studies by Tan, Goh, Chia and Treagust (2002), they observed that the 2-tiered test was better able to show their students‟ alternative conceptions and change in conception after an intervention was administered. Similar observations were made by Voska and Heikkinen (2000), and Rahayu, Chandrasegaran, Treagust, Kita and Ibnu (2011) in studies on acids and bases, Treagust, Chanrasegaran, Crowley, Yung, Cheong and Otham (2012) on Kinetic Particle Theory, and many more when they administered two-tiered tests to uncovers student misconceptions. In the TTT, examinees are required to justify their choice of answers, thus, enhancing the robustness of the test. In the current study, if only the MCT had been used, 26% of the trainees who had poor conceptual understanding of the topics under study would have passed for understanding the concepts, which is deceptive. Major Findings showed that vast improvements in trainees" conceptual understanding of the topics under study were made in the post TTT. From Treagust"s (2006) studies in Australia and other parts of the Western world, it has been discovered that diagnostic tests have the ability to discern between students" choice of answers as being reasoned choices or not. Some of the improved conceptual answers provided in the reasoning part of the developed 2-tiered diagnostic test for this current study could be found in Appendix K. A significant positive change in score is a quantitative indication of how far a student has gained on in cognition and a subsequent gain in conceptual understanding (MF 6 & 10). An analysis of the post TTT scores on the surface may seem that trainees performed poorly as compared to the post MCT. This was not really so. Trainees had to score both parts of a test item to indicate adequate understanding of a concept. If they scored only one part, they were given no mark because of the one-part wrong answer. However, they seem to have performed so much better in the post-test than in the pre-test. This could be attributed to higher gains in conception of the topics treated, due to the intervention of micro chemistry equipment which was administered. This assertion is supported by statistical analysis of the diagnostic tests.

**Research Question 2**

**What skills would teacher trainees who are trained to use micro chemistry equipment for practical activities demonstrate in developing their practical activities?**

Research question one was answered by MF 12, MF 13, MF 14, MF 15, MF 16, MF 17, MF 25 and MF 28 as indicated in Chapter Four. From the activities performed by the trainees, majority of them demonstrated the following skills:

1. Concept skills, process skills and laboratory skills (MF 13 & 28)
2. Analytical and predictive skills (MF 14, MF 30 & MF 28)
3. Planning skills (MF 16)
4. Time management skills (MF 14 & 15)
5. Critical thinking , reflective and deductive skills (MF 30, MF 25, MF 28)
6. Interactive skills, collaborative skills, manipulative skills, and concept skills (MF13, MF 14 & MF 15)
7. Learning skills (MF 15 & MF 17)
8. Design and development of practical activities (MF 16)
9. Interpretive skills (MF 14, MF 16 & MF 28)

It was observed that the trainees developed 16 main skills through MCE-based practical activities. These skills were crucially, interpretation of practical activities. For instance, the trainees were able to understand and identify the main requirements for setting up an activity to determine the action of water on group one, group two and group thirteen metals. Those who understood the concept were able to link the idea of loss of electrons to their understanding of electrode potentials. A similar case of demonstration of interpretive skills was observed in an organic chemistry class by Zakaria, Latip and Tantayanon (2012) in Malyasia. In their case, first year undergraduate students were able to interpret laboratory instructions, design and carry out organic chemistry experiments successfully on their own. In a comparable situation in Mozambique, teacher trainees were observed to have used MCE and demonstrated great interpretive and planning skills when they were given some metals to determine their general chemical reactivity (Kombo, 2006). Those trainees who could not interpret the requirements of assigned activities showed misunderstanding of the design instructions, and so wrote wrong equations which they failed to balance correctly. Their interpretation was based on a conceptual understanding of the chemical interaction between water and the metals in order to assume possible outcomes. If learners succeeded in making successful interpretation of laboratory instructions, then they would be said to have demonstrated critical thinking and deductive skills through correct conceptual interpretation and analysis (Zakaria, Latip, & Tantayanon, 2012).

Trainees also demonstrated planning skills. To demonstrate these skills, trainees had to show organisational skills based upon their interpretive skills. In the case of the periodicity activity, they were able to fill their comboplates with water and observe the action of water on equal sizes but different pieces of metals in succession, and then at about the same time also. Success in designing and executing the activity in a sequential manner to enable them to clearly observe the trend or patterns in the behaviour of metals was seen as having developed a planning skill. Doing the activity in a haphazard manner was not to have shown a good planning skill because it would not allow one to observe the periodic trend clearly. Similarly, when Tanzanian secondary school students were given plastic sheets and ionic compounds to determine their solubilities through the microscale approach, successful students were able to plan and design their activities based upon concepts such as dissolution, precipitation reactions, and common ion effect (Mafumiko, 2008). Students who failed to obtain relevant results were found to be those who had no prior planning ideas in performing their activities. These students were finally able to draw logical conclusions only after practice and skilful plan of their work.

Many other skills were also acquired and demonstrated by the trainees. With the acquisition of interpretive and planning skills, other skills such as reflective skills, critical thinking skills, deductive skills, learning skills, analytical skills, and time management skills were acquired and demonstrated. The reflective aspect of the MCE activities offered the trainees the opportunity to analyse their own experimental results, draw informed conclusions and think about possible limits to generalisations. This was a novel introduction into the UEW Chemistry department practical sessions. Appropriately designed practical activities can be effective in promoting cognitive skills, practical skills, interest in chemistry and interest in knowing about chemistry. According to Hanson and Acquah (2014) ability to analyse and interpret data correctly in a process lab leads to the development of conceptual gains. Herrington and Nakhleh (2003) also support the above view that practical activities equip learners with learning skills that facilitate conceptual understanding as they observed among American students who carried out activities in organic chemistry. Antwi (2013) added that if students were able to execute expected learning indicators and skills then they would be able to critically evaluate and gain knowledge. At the end of each lesson, concept labs became sufficiently clear and acceptable to learners as observed by Hofstein, Shore and Kipnis (2004) in a similar study on high school students" attitudes towards science activities and how it affects their conceptual development. This conceptual study agrees with Lemke (2007), who affirms that if students gain deep conception through practical work, they invariably gain knowledge for transfer to other areas of study.

The MCE approach significantly enhanced the selected Ghanaian undergraduate teacher trainees‟ understanding of chemistry concepts through cognitive conflict resolution as was observed among Tanzanian high school students in Mafumiko‟s (2008) MCE study. During the trainees‟ study of periodic chemistry they were able to build concept frameworks involving concepts such as period, group, atomic radius or size, ionisation energy and electron affinity by listing the attributes of the concepts under study. The conflict situations required the trainees to develop analytical, reflective, critical thinking and deductive skills, as demonstrated by students who engaged in micro-computer based laboratory activities in five European countries, as reported by Tortosa (2012). In Tortosa‟s report, European high school students used micro equipment to increase their skills of manipulation, observation and explanation to measure pH levels and salinity in water and then desalinate it. They carried out other activities on chemical equilibrium and gas laws. If the students succeeded in predicting answers to foci questions and transferred the knowledge acquired to solve other non-situational questions (translation and reflection) with the same underlying concept, then they were said to have adequately demonstrated manipulative, reflective, analytical, critical thinking and deductive skills. All of these demonstrations or activities were reflections of higher order thinking. For example, if a student could combine principles of stoichiometry with the ideal gas law or the concept of molarity, or perhaps determine the mass of a liquid based on its density and measured volume, then according to Zoller and Pushkin (2007), such a student illustrated higher-order thinking. In this study, trainees were confronted with the problem of identifying as many as six unknown solutions from ionic compounds. They had to discuss (collaboratively) the possibilities based upon other activities that they had carried out, their prior knowledge on the solubilities of ions, and then transfer such knowledge to solve the given puzzle. This demanded a lot of ingenuity, collaboration, reflection, and analysis before a deduction could be made. At the end of each practical activity, trainees were expected to be able to draw their own logical conclusions from the MCE activities and make a good reflective report. If the micro chemistry activities and reflective aspects were successfully executed, then reflective skills were said to be acquired. This learning approach was used by other researchers such as Hanson and Acquah (2014) in Ghana, Mafumiko (2008) in Tanzania, and Miyake (2006) in The Netherlands to enable students to demonstrate acquired skills in other related practical activities. In this study, trainees collaborated affably and completed assigned activities correctly and on time; thereby demonstrating the additional acquisition of time management skills. They demonstrated collaborative and cooperative skills toward a common learning goal. Such collaborative skills have been known to lead to concept gains in conceptual development studies in Tanzanian High schools where cooperative skills enabled Form five students to work in pairs on solubility and precipitation activities (Mafumiko, 2008). Similar acquisition of skills through practical activities were exhibited by students in South African primary schools (Bell & Bradley, 2012), and in some European schools as observed by Ding and Harskamp (2011) and Miyake (2006). Inability to acquire collaborative skills could lead to the formation and retention of alternative concepts as was discovered in a study by Ding and Harskamp (2011) in The Netherlands. In their research, their control group which performed activities individually performed below their collaborative and peer-tutoring counterparts in their understanding of chemistry concepts. Similarly, in Hanson and Acquah‟s (2014) investigation on the effect of the acquisition of collaborative skills among teacher trainees in Ghana, they found that their experimental group which worked collaboratively acquired skills which led to higher conceptual gains than those who studied individually. Hanson and Acquah‟s findings confirm the outcomes for this present study as well as findings intimated by Ding and Harskamp (2011) in their study of Dutch students. Hofstein and Lunetta (2004) add that an interactive and collaborative lab, as a unique social setting, has great potential to enhance social interactions that can contribute positively to cognitive growth. As reiterated by Hofstein (2004), appropriately designed practical activities can be effective in promoting cognitive skills, practical skills, interest in chemistry, and interest in knowing about chemistry.

Although the trainees were using the MCE approach for the first time, their dexterity with the use of the equipment and ease of use, indicated that they had acquired the desired manipulative skills which could lead to cognitive gains. Similarly, Zakaria, Latip and Tantayanon (2012) found out from their studies in Malaysia that undergraduate students who acquired manipulative skills were able to work more confidently, appeared to be at ease, and made higher gains in cognition. Their acquired skills in handling small scale equipment during their organic practical activities made them equally careful in working with macro glass equipment than students who had no prior experience with micro equipment, as was discovered by Kelkar and Dhavale (2000) in a comparative study in India. How efficiently the trainees were able to acquire the needed skills to develop other MCE practical activities was summed up in their success at designing activity sheets similar to what they worked with at the end of their study. In Kombo‟s (2006) micro science kit activities with distance education teacher trainees in Mozambique, he also discovered that the trainees developed the requisite skills to design and develop their own activities when they returned to campus for their face-to-face interaction.

The demonstration of conceptual skills through the MCE approach was gathered from how the trainees exhibited process and lab skills through planning and designing of activities, the way they executed their designs practically, their interpretation and analysis of experimental results as well as how they presented their laboratory reports. Other skills that they demonstrated, which indicated conceptual understanding, were appropriate analysis, the application of their findings to other situations, processing of data, explanations of relationships and development of generalisations.

As evidence of the demonstration of process skills, the trainees in this study generated and validated knowledge experimentally. Skills labs were demonstrated through techniques such as the assemblage of equipment, demonstration of laboratory procedures and dexterity with the use of the MCE. According to Hofstein and Lunetta (2004), ability to analyse and interpret data correctly in a process and skills lab leads to the development of conceptual gains as was observed among the trainees in this study. Likewise, Herrington and Nakhleh (2003), from their study of American students, support the above view that practical activities equip learners with learning skills that facilitate conceptual understanding. Kombo (2006) assessed the learning and conceptual skills of students in the Mozambique, by asking them to analyse data, reduce tables, design appropriate tables, make conclusions, generalise, identify weaknesses in them and suggest follow-up questions. The Mozambican trainees who demonstrated these skills successfully were deemed to have acquired the requisite skills. In a similar manner, Ghanaian teacher trainees were able to critically evaluate their activities and made decisions regarding relationships between variables, for the generation of hypothesis and knowledge in their interaction with the MCE. For example, in the current study, the trainees were able to design techniques for avoiding spillages which could result in contamination of chemicals and alteration of results. They were also able to design appropriate tables for recording their data. They defined concepts, listed their attributes and specified their relationships with others. Thus, knowledge was generated and validated experimentally through their intellectual and process skills. According to Mafumiko (2006), concept skills and process skills must work together for each to be achieved. This practice was also used with success by Kombo (2006) in Mozambique and Hanson (2014a) to enable learners to demonstrate their reflective and concept skills.

In conclusion, it was possible to use MCE concept-based activities to promote thinking and learning skills for conceptual development. Equipping learners with the necessary requisite learning skills through practical activities facilitates sound concept formation. The outcomes of this study confirmed findings from studies carried out by researchers such as Bradley (1999b; 2001), Kombo (2006), Mafumiko (2006; 2008), and Zakaria, Latip and Tantayanon (2012), to name a few, where students who had practical engagement with MCE demonstrated many acquired skills.

**Research Question 3**

**What types of chemistry concepts would emerge out of the trainees' understanding of practical activities they perform?**

This question was answered by MF 3, MF 4, MF 13, MF 16, MF 18, MF 19, MF 20, MF 21, MF 22, MF 23, MF 24, and MF 25 which show that both alternative and scientific concepts emerged out of the trainees" understanding of activities that they performed. Major Findings 3, 4, 13, and 20 revealed the trainees" poor conceptual understanding of five out of the eight topics in the MCT and all the eight topics in the two-tiered test (TTT). Some of the important thematic alternative concepts that emerged out of practical activities were:

1. Neutral salts give neutral aqueous solutions (MF 18)
2. Mole ratios are dependent on concentration (MF21)
3. Inability to provide categorical distinctions for the theories of acids and basis. That is, Lewis acids and bases must donate and accept protons and not electrons the Bronsted-Lowry concept could be used to explain all acid and base reactions as well as chemical properties (MF 20)
4. Subscripts assumed as number of moles and the mole defined as a molecule (MF 21, MF 24)
5. Misunderstandings about the relative strengths of inter and intramolecular bonds
6. Comprehension of states of matter and the idea of „invisibility" of gases (MF 24)
7. Confusion over the particulate nature of matter and corresponding units (MF 24)

8. The ratios of coefficients used in some stoichiometric calculations as against subscripts used in other instances (MF 21)

Other identified alternative and scientific concepts have been presented in Appendices K-N. (These concepts have not been categorised into the five types of misconceptions as identified by Gooding and Metz, 2011). Similar alternative concepts were identified by Taber (2002) in the United Kingdom among Advanced Level students when he administered a concept test on the nature of matter and ionisation energy. Bell and Bradley (2012) likewise, noted almost the same conceptions among high school students in South Africa and other African countries.

Some scientific concepts emerged when the trainees engaged in MCE activities on chemical stoichiometry, periodicity and the particulate nature of matter. The MCE lab experiences were found to be superior for providing trainees with skills as was observed by Singh, McGowan, Szafran and Pike in India (2000), Hofstein and Mamlok-Naaman (2007) in Israel, and Taraban et al (2006). Group discussions and repeated practice, as proposed by Kolb and Kolb (2005), were considered important ingredients in this study for uncovering and forming concepts through the MCE activities. Gerjets, Scheiter and Catrambone (2004), reiterate that regular practice and studying by examples contribute to the formation of memorable patterns and subsequently, the formation of sound concepts

For example, the application of Kolb and Kolb"s (2005) experiential theory worked in line with the MCE approach in this study to afford trainees the opportunity to experiment, try out their own ideas, engage in positive cognitive conflicts and re-orient their perceptions with an „ahaa" or „I now get it" expression. Through repeated self-practice the trainees in this current study were able to identify their own alternative conceptions and built sound conceptions in basic inorganic chemistry. They explored physical phenomena on their own, as a starting point for personal construction of meaning as discovered by Duit (2011), and Wellington (2007). According to Wellington (2007) laboratory activities make abstract chemistry concepts concrete and comprehensible. Concept formation cannot emerge with adequate levels of conceptual explanations without access to an array of learning materials that offer hands-on and minds-on experiences (Taraban, Box, Myers, Pollard, & Bowen, 2006). This assertion is supported by findings from a strand of research on active learning by Keyser (2000) which expounds on the effectiveness of practical activity on understanding, acquiring, and retaining, enhancing or generating new knowledge. Findings from studies by Huber (2001), Abdullah, Mohamed and Hj Ismail (2009), Bell and Bradley (2012), on the development of practical activities emphasise that chemistry practical activities enhance the emergence of concepts and ideas gained form theoretical exposition. Reid and Shah (2007) adduce that chemistry laboratory practice course must be seen as a whole and experimental experiences introduced to develop outcomes that will enable students to form concepts. They added that practical work is considered as one of the processes by which students‟ science concept formation and transferable skills are enhanced and applied in future life (Reid & Shah, 2007). Herrington and Nakhleh (2003) conclude from their American high school study that practical activities singularly or jointly (with other modes) facilitate the acquisition of conceptual understanding and learning skills. This is because science practical activities allow students to change their initial understanding of scientific concepts through the creation of association, similarities and confirmation of distinctions. This implies that students who engage in practical activities to gain understanding of scientific concepts are likely to apply them to their daily life activities. It also implies that students will be able to apply the knowledge they have acquired to novel situations. Practical activities, as a form of instructional strategy, thus help students to increase their understanding and application of many phenomena around them through practice.

The development of conceptual knowledge through practical activity is important in chemistry learning. Students‟ chemistry concept formation is crucial for the development of self-confidence in becoming seasoned scientists (Bereiter, 2001), since conceptual knowledge helps to build students‟ reasoning power and decision-making ability. In all, many sound concepts emerged out of the trainees‟ activities on acid solutions, base solutions, periodicity, chemical bonds, equations, chemical stoichiometry, solubility and pH topics. The only concept, for which the trainees‟ conceptual understanding did not show up prominently, by the end of the intervention, was „hybridisation‟. This could have been because there was no direct MCE activity on hybridisation. Nevertheless the MCE approach enabled trainees to make logical scientific deductions about the concepts.

**Research Question 4**

**What characteristics of the microchemistry equipment activities would be suitable for developing a teaching manual?**

This question was answered with Major Findings MF 15, MF 16, MF 17, MF 25, MF 26, MF 27, MF 28, MF 29, Mf 30, and MF 31. From the trainees responses to the suitability of developing a teaching manual based on the use of the MCE, the following 18 attributes of the MCE and MCE experiments were identified:

1. Robust nature of the equipment and availability (MF 31)
2. Shorter activity times (MF 15, MF 27)
3. Cost effective (MF 30)
4. Easy to use for activities (MF 16, MF 27, MF 31)
5. Flexibility of approach (MF 30)
6. Concept-based activities (MF 17, MF 25, MF 29, MF 30)
7. Skills-based learning (MF 16, MF 27, MF 28, MF 30)
8. Individual and collaborative practice (MF 29)
9. Interactive nature (MF 15, MF 17)
10. Usefulness (MF 26, MF 31)
11. Fun (MF 31)
12. Useful for deprived or less endowed communities (MF 30)
13. Effective for use in large classes (MF 29)
14. Possibility of its use at lower levels of education -basic school/early childhood (MF 27, MF 30)
15. Simple (MF 27, MF 31)
16. Inherent precise and critical nature (MF 27)
17. Logical and deductive skills inherent (MF 25)

18. Versatile for use at all levels of education (MF 30, MF 31)

When the teacher trainees were asked for their opinions on the micro chemistry equipment‟s suitability as a tool for the development of a concept-based teaching manual, 18 attributes of the MCE were identified. About 88% of the trainees spoke highly about the MCE approach as a useful tool for developing a teaching manual by attesting that it made room for high class interaction, ample practice and stepwise activities (MF 29). In Kombo‟s (2006) research about the usefulness of adopting MCE activity-based manuals for use in a teacher training institution in Mozambique, similar observations were made. Majority of his participants opted for the adoption of MCE practical manuals because of their ease of use, less running cost, versatility and other numerous benefits. Almost all the trainees in this current study ranked the MCE as robust, safe and simple to use (MF 27, 31). A vast majority of trainees said that the MCE curriculum materials were easy to interpret and apply. Many others also said that it helped them to uncover, refute their wrong ideas, and confirm some chemistry concepts. In effect, the MCE was a good tool which tested and confirmed concepts that they knew, leading to increased concept development. Almost all of the trainees stated that the MCE practical approach yielded faster and observable feedback. Mafumiko‟s (2006, 2008) studies about Tanzanian secondary school students who used MCE attested to its several attributes just as the Ghanaian teacher trainees did. The participants in both studies implied from their reactions that the MCE had unique attributes and so MCE-based activities could be compiled into a manual for use in schools to enhance concept development. This observation about the practicality of the construction of an MCE-based teaching manual was evident in Kombo‟s (2006) MCE study with Mozambican teacher trainees.

The Ghanaian trainees further intimated that the MCE activities encouraged critical thinking as it enabled them to discriminate between facts in order to make correct choices. Positive statements such as „it helps to confirm correct concepts very quickly‟, „it sharpens observational and manipulative skills‟, „more conceptual gains than in the traditional lessons‟, „builds accuracy and precision‟, pre-lab enables focus and recall‟ are all examples of positive comments made by more than half of the population. Overall results showed that the trainees reacted favourably to the use of the MCE materials and approach as having capacities upon which a manual could be developed. In an interview with trainees, some said that they would design and document activities for use in their schools as soon as they assumed teaching after their undergraduate training as was intimated by teacher trainees in Kombos‟s (2006) studies. A further probe into why they would choose MCE activities over other traditional activities evoked responses such as the economically small-sized nature of the equipment, its robust nature, the possibility of using it with children, among others as attested by participants in Bradley‟s (1999) studies on the use of the MCE in South African schools. Another major characteristic of the MCE, which featured prominently in the aspects of the micro equipment which could be suitable for developing a teaching manual, was its inherent short activity period. The Ghanaian trainees were of the view that they could capitalise on this positive attribute to develop a teaching manual for other teachers, especially for those in primary schools and deprived communities as MCE activities were cost effective.

Some of the interesting comments made by trainees in support of the benefits of the MCE in an interview were that, „it was possible to do activities with a large number of students because minimum resources would be used‟, „it was a cheap equipment and could be afforded by parents and school children‟, and „it was good for conducting practical work as it engaged trainees actively and thoroughly". They discussed other issues such as easy disposal of reaction products, flexibility of the approach and possibility of pre-lab because of the relatively shorter activity periods. Similar observations were made in studies by students who participated in a micro scale activity in pollution studies in Lake Erie (Tallmadge, Homan, Ruth, & Bilek, 2004). The trainees in the current Ghanaian study intimated that MCE activities were fun and could be completed in relatively shorter times. Gebrekidan, Lykknes and Kvittingen (2014) and Yoo et al. (2006) had similar responses from their study participants in the Ethiopia, the Southern part of Africa and the Western world. Their participants were all highly enthused with its use and found it useful in conducting practical activities. They adduced that they would attempt to put together series of MCE-based activities in their schools for use. These positive comments about the MCE go to prove its suitability for developing a teaching manual for schools in Ghana.

The implication here is that several attributes of the MCE approach could be useful for the development of MCE activity manuals. In conclusion, majority of the trainees expressed their desire to develop similar MCE-based worksheets for use and build them up into manuals for use in their schools in future.

**Research Question 5**

**Would teaching through the MCE approach significantly change the way the selected inorganic chemistry topics are learned?**

This question was answered with Major Findings MF 10, MF 11, MF 12, MF 13, MF 14, MF 16, MF 17, MF 18, MF 19, MF 20, MF 21, MF 22, MF 27, MF 28, MF 29, MF 32, MF 33, MF 34 and MF 35. This question sought to find out the statistically significant impact of the intervention on the trainees. In order to assess whether the gains made in the post-intervention tests were significant or not, ANOVA and t-tests were carried out on gained scores made in tests and other exercises. Paired samples results indicated significant differences between the two kinds of scoring modes used in the two-tiered diagnostic concept test. The TTT proved to be a more superior way of assessing students to unearth their prior conceptions for conceptual change and understanding of taught concepts. Trainees" performances in tests were assessed for significance change as it is a direct reflection of their understanding of concepts in a concrete way. Significant gains were made in trainees" conceptual understanding of some inorganic chemistry concepts under study after they engaged in MCE practical activities; ($t(47) = 4.233$, $p < 0.05$) with post-test scores higher than the pre-test scores, at a 95% confidence interval of the difference. Some findings which attest to the fact that the MCE could significantly change the way that inorganic chemistry is taught are:

1. Trainees could not apply concepts, terms and science language appropriately, but were able to do so after their interaction with the MCE (MF 13, MF 20, MF 35)
2. Their process, concept and lab skills increased tremendously on the concepts of periodicity, acid-base reactions and stoichiometry and so could explain events scientifically (MF 14, MF 18, MF 19, MF 21, MF 22)

3. Trainees made increased conceptual gains in their learning due to their personal understanding from their interaction with the MCE (MF 8, MF 9 MF 10, MF 11, MF 12, MF 35)
4. Significant upward gains of 20.6 units were made in the post-intervention test (MF 33, MF 34)
5. Gathered opinions from trainees indicated that they had positive views about the possibility of the MCE approach causing a big positivive change in the teaching and learning of inorganic chemistry (MF 16, MF 17, MF 27, MF 28, MF 29, MF 35)

The data for descriptive means indicates that trainees had comparatively lower scores in pre- and post-test as well as changed scores in the TTT than in the MCT. Low mean values for TTT were 34.21 and 54.79 as compared to 59.77 and 65.28 for the MCT. Changes in students‟ scores were all significant with respect to improved performance at the time this data was taken. A statistical analysis of scores in the MCT and TTT gave an overall picture of trainees‟ marked improvement in cognition with the use of the MCE. While statistical change among trainees in the MCT was 0.91, change in the TTT was 0.001. The latter indicates a high significant change or improvement in trainees‟ ability to make reasoned choices in selecting answers after their interaction with the MCE. Comparative analyses showed that trainees‟ cognition generally improved with the use of the MCE approach, as indicated by the MCT and TTT scores. The mean differences between scores are lower with the TTT after trainees‟ engagement with the MCE but still higher than in their pre-intervention scores. This indicates a positive change in cognition with the use of the MCE, which could thus, be advocated as a good conceptual change tool for adoption.

An analysis of changed scores only (Appendix O) shows that not much change in cognition was made with respect to trainees" performance in the MCT. The frequency of probability, F was 0.566 which is higher than the determinant value. The significant value which should be less than 0.005 to prove that a significant change had been made was 0.907. However, the significance value for the TTT changed scores was 0.001. In effect, trainees" cognition generally improved with the use of the MCE approach as indicated by an analysis of the MCT and TTT changed scores. The mean differences between scores are lower with the TTT after use of the MCE, indicating a positive change in cognition with the use of the MCE. Paired samples correlations showed significant differences between the MCT and TTT changed scores. It means in simple terms that the TTT significantly was able to assess how trainees" reasoned in making choices of correct concepts as well as an improvement in their scientific reasoning abilities after using the MCE.

**Summary for Chapter Five**

This chapter presented the discussion of the field study carried out to evaluate the impact of the MCE on the teaching and learning of inorganic chemistry concepts in a Ghanaian University. The impact of the approach was assessed by looking at the actual implementation of the approach, the opinions of trainees, their experiences and their learning outcomes. The outcomes portrayed that they had positive experiences with the MCE. They acquired many skills through the use of the simple, robust, versatile equipment, and were able to debunk some of their alternative conceptions, while affirming others. According to Bradley (2000), using simple and easy-to-handle equipment, like the MCE, distracts students as little as possible and enables them to concentrate on discovering and building up of concepts. The results for the TTT proved a dual purpose. They show more clearly, gains made by trainees, as well as how much gains they made with respect to the MCT. In simple terms, the TTT proved to be a good diagnostic test; distinguishing what students know from what they do not know. It also showed how much trainees could choose correct reasoned answers to choices made in the MCT. The outcome of the diagnostic test as evidenced in works of Mclary and Bretz (2012) offered opportunity to gain insight into the trainees‟ learning models. It actually helped to unearth their alternative concepts. The paired sample correlation result for the changed scores in both diagnostic tests prior to, and after the intervention, also showed that indeed engagement with the MCE was a significant factor in enhancing trainees‟ conceptual understanding of selected inorganic chemistry topics.

The MCE promoted an active learning environment as well as opportunities for trainees to interact with each other, with materials, and the teacher. This increased their confidence in performing practical activities which subsequently enhanced their critical thinking and higher learning skills. They were of the view that they could translate these attributes and lessons gained into the development of teaching manuals.

# CHAPTER SIX

## SUMMARY OF FINDINGS, CONCLUSIONS & RECOMMENDATION

### Overview

The summary of the findings for this study, conclusions drawn from the findings, uniqueness of the study and recommendations have been presented in this chapter. The micro chemistry equipment (MCE) approach was introduced as an intervention through ten lessons and activities with adequate support materials to change the way chemistry was taught and studied conceptually. Thus, participants demonstrated diverse acquired learning skills and scientific concepts at the end of the study. Suggestions for further studies have been provided.

### Summary of major findings

The development and use of novel teaching materials to enhance teaching and learning form an important part of the educational system in any proactive environmental community or nation. Accompanying curriculum materials that often come with these novel changes serve as concrete examples and support for teachers in understanding the meaning and interpretation of the changes, especially at its initial phase. In this study, such curriculum materials were developed to make the use of the MCE lessons and its suggested activities more user-friendly to both teachers and teacher trainees to enable the trainees develop chemical principles. The teaching manuals used in this study contained suggested lesson notes which had introductory, development and concluding sessions. In addition, they contained diagnostic concept questions that could unearth trainees" conceptual problems. More importantly, the developed teaching manual contained suggested scientific answers as a guide to correct identified alternative concepts. The focus of this study was undertaken to explore the use of micro chemistry equipment in chemistry practical activities to improve on trainees‟ understanding and application of chemical principles. In effect, the study was to address the possibility of using micro chemistry equipment experimentation to solve the problem of ineffective practical activities in Ghanaian schools and universities, especially in remote regions. The features of the MCE were such that it could be used for simple, cost-effective activities, with very little instruction at all levels of education, as well as in less endowed communities. Therefore, it was important that pre-service teachers learned how to manipulate the simple, easy-to-handle micro equipment to enable them use it in diverse ways to facilitate learning in future and develop their own personal understanding of chemical concepts.

In this study, the use of MCE materials was employed to enhance conceptual understanding during ten inorganic chemistry lessons. The study was meant to enable trainees acquire some practical skills through the use of the micro chemistry equipment. The MCE served as a tool in the learning of selected chemistry topics and concept development in chemistry. It was also to equip participants with skills for developing their own activities for concept development among students in their classrooms. The design of the study was an action research which a batch of teacher trainees in UEW participated in. The instruments included pre-intervention test, post-intervention test, observation, questionnaire and interview.

The results of the study indicated that the trainees were able to perform MCE activities in lessons based on topics such as chemical stoichiometry, molecularity, solutions, pH and periodicity, and demonstrated skills such as analytical, predictive, planning, critical thinking, reflective, interpretive and time management skills. Through these weekly MCE-based lessons and activities they became conscious of some of their alternative conceptions in basic inorganic chemistry. Alternative concepts which were identified in the 2-tiered diagnostic concept test were found to be persistent as most of them recurred in their first few practical activities. However, most of these persistent alternative concepts gave way to more scientific concepts through constant practice with the MCE and MCE-based activities. Kolb, Boyatzis and Mainenelis (2001) suggest that repetitive practice leads to the creation of knowledge through transformed experience. Results obtained from the MCE activities suggested that the approach had potential practicality in the participants‟ real work as teachers in their schools. The trainees‟ logical reasoning responses to questions improved systematically from the beginning of this study to the end. This reflected an understanding of the concepts that they studied. The findings of this study are summarised as:

1. Demonstration of dexterity with the use of the micro chemistry equipment
2. Demonstration of laboratory, process and concept, analytical, predictive, deductive, interactive, time management, reflective and critical thinking skills
3. Ability to design some of their own practical activities.
4. Demonstration that the MCE activities were very interesting, easy-to-understand, required less work time, was less sophisticated and could be used in the classroom as well as in a laboratory.
5. Ability to use the MCE in resource constrained environments. This is because MCE employs small amounts of chemicals, uses cheap and easy-to-handle robust equipment and can be used in classrooms or even under trees.
6. The discovery of a promising way to motivate teaching and learning of chemistry in the University of Education, Winneba and its allied practice schools.

7. The trainees could perform activities on their own with little help or interference from their teacher and the equipment. This increased their confidence as observed in a similar research report by Yoo, Hong and Yoon (2006).
8. The trainees gained first-hand experience in working systematically to arrive at scientific truths as they did with the relationship between mole ratios and concentrations of solutions. For the first time, they did not have to learn concepts by rote. This reflects Hofstein and Lunetta"s (2004) assertion that the use of MCE experiments has the potential to promote active classroom learning environment through small group activities.
9. It was observed that the trainees" involvement in practical activities led to greater understanding of principles in the study of chemistry as Demircioglu, Ayas and Demircioglu (2005) observed among Turkish students.
10. Majority of trainees admitted that they now understood the concepts which underlie acid-base neutralisation reactions, the stoichiometry of reacting species, and their application in qualitative analysis, as well periodicity.

**Conclusion**

From reviewed literature, it was gathered that exposing learners to new ideas, resources and opportunities broadened their own awareness of possibilities for change and improvement (van den Akker, 2004; Mafumiko, 2008). The trainees" opinions proved that the MCE approach was not only easy to use but made chemistry lessons more interesting, interactive and very sociable. Participants developed analytical and logical reasoning skills because of the systematic way in which their MCE practical activities were designed. The designed curriculum materials provided enough structure and support for the trainees and ensured that trainees worked through less difficult to more complex problems collaboratively. In all, the MCE approach was seen as a powerful method in changing the face of teaching and learning of inorganic chemistry. For effective teaching and learning, students have to be motivated to be intellectually active so that they develop functional understanding. This was achieved when trainees were allowed to reflect on their initial alternative answers on some concepts after they had gained better conceptual understanding. Thus, understanding of how learners put pieces of information together, encouraging individual reflection, metacognition and acceptances of alternatives as they engage in interactive activities will go a long way to help learners build authentic science concepts.

A challenge faced by the Researcher was the conversion of standard laboratory activities to guided concept-based MCE activities. This was solved through clear identification of the three main labs with definite activity goals for each.

On the whole, the teacher trainees of UEW viewed the MCE intervention positively because of its hands-on and concept-based approach. Participants made significant gains in their performance in concept development, which is an indication of their improved understanding of chemistry concepts. This study has shown that the way the MCE lessons were developed offered more effective approach in helping trainees gain understanding of basic inorganic chemistry concepts as compared to traditional scale practical work.

## Recommendations

Findings from this study are significant for the improvement of chemistry teaching and learning in UEW. Based on the findings, the following recommendations are made:

### Strategies for conceptual change

The importance of students‟ prior knowledge in learning has been emphasised. It is, thus, recommended that prior to the teaching of every topic in basic inorganic chemistry teachers should be aware of existing conceptions through the use of two, three or four-tiered diagnostic tests. Experiments that challenge students‟ existing ideas about chemistry concepts should be developed to bring out students‟ existing naïve conceptions.

### Curriculum

In view of the outcomes of this study and how the use of simple equipment facilitated conceptual understanding, the use of MCE could be incorporated into all science curricula by the Ministry of Education and the Centre for Research and Curriculum Development Division. Curriculum developers should be involved in the design and choice of equipment to suit educational programmes. An MCE teaching and practical manual, based on the present chemistry curricula and examination syllabus, could be developed for use in schools through experts‟ guidance. This will require a reconsideration of the examination system in Ghana.

### Cost of MCE

The cost of MCE is far less than that of the traditional standard equipment and would therefore, pose little problem for schools that intend to adopt them. Besides, local materials could be used for a start to ensure the promotion of the programme. The net profit that could be made over a long time from investing in MCE, as against traditional equipment, would be enormous.

**Science teacher education**

Practical work involving MCE will not result in concept learning by students unless the teacher is able to help this process happen (Bradley, 2000). To effectively support this, teachers must experience the MCE approach in the context of their chemistry learning in their various training institutions. The introduction and practice to get acquainted with the use and benefits of the MCE could be through their science methods class. To do this, their MCE curriculum materials could be used as learning resources or as example of a promising strategy for practical work in low resourced environments (Mafumiko, 2008).

**Recommendations for future research**

1. This research proved, though implicitly, that collaboration among students promotes active chemistry learning and concept formation in chemistry. It would thus, be good to investigate the cognitive impact of the MCE approach on collaborative learning. Developing a better means of measuring student achievement, which will be based solely on the MCE approach and collaboration, would also be beneficial.

2. The MCE approach could be extended to other chemistry topics, especially those where many alternative conceptions have been reported in other literature. For example, other physical and inorganic chemistry topics like equilibrium of aqueous solutions (Haider & Al Naqabi, 2008), electrolysis (Abdullah, Mohamed, & Hj Ismail, 2009), precipitation reactions and solubility (Taber, 2009), which all lend themselves to the use of MCE could be studied.

3. A longitudinal as well as cross-sectional study of selected students‟ conceptions of principles in chemistry from general chemistry to analytical chemistry is recommended.

4. Learners‟ identified alternative concepts from a similar diagnostic test could be categorised into the five types of misconceptions as identified by Gooding and Metz (2011).

5. A study could also be carried out on the efforts of teachers in the implementation of the MCE and its accompanying active strategies in their classrooms as well as their effect on students‟ conceptual understanding.

**Contribution of the study to knowledge**

Micro Chemistry Equipment (MCE), also called small scale equipment by IUPAC and micro science kit by others are small-sized labware for laboratory activities. Thus, microscale chemistry involves conducting laboratory activities using significantly reduced quantities of chemicals. IUPAC has attempted to popularise the use of MCE through several workshops and conferences in the Western world and some parts of Africa (Bradley, 1999a; 2001; Kelkar & Dhavale, 2000; El-Marsafy, Schwarz, & Najdoski, 2011). Most of the researches into the adoption and use of MCE used them for reasons as for the replacement of macro orthodox glass labware, while others used them basically because of their low cost in Africa (Engida, 2012; Sileshi, 2012; Yitbarek, 2012). Even in industrialised Europe, particularly France, the MCE have been used for such a purpose as cutting down cost (Tallmadge, Homan, Ruth, & Bilek, 2004; Huang, 2007; Engida, 2012).

Other researches into the plausible use of MCE have used them as tools for transforming the curriculum (Kombo, 2006; Mafumiko, 2008). A few have used the

MCE to compare the differences in the cost of using MCE vials as against standard burettes (Singh, McGowan, Szafran, & Pike, 2000). Abdullah, Mohamed and Hj Ismail (2009) have done an extensive work on MCE in Malaysia to enhance collaboration among students as well as to teach certain topics such as rates of reaction, ethanol and ester preparation, exothermic and endothermic reactions and soap preparation. Their emphasis for the use of MCE was in terms of amount of chemicals used, waste produced and time saved. These activities were all conducted in secondary schools in Malaysia. Similarly Tallmadge, Homan, Ruth and Bilek (2004) studied the effect of MCE on pollution in the environment among high school students in the UK. However, Zakaria, Latip and Tantayanon (2012) went further to study the use of MCE among undergraduates in an organic chemistry course in Malaysia. They found that it was feasible for use in the study of organic chemistry in the university as generally minute quantities of organic chemicals are required for organic reactions. Reid and Shah (2007) have done extensive studies on the role of university laboratory work, but did not use MCE in any of their studies nor did they connect them to concept development. Studies on the use of MCE by Kelkar and Dhavale (2000) in India proved that it could enable students to change their negative attitude to science and enable them acquire some manipulate skills. So far, none of the above researchers developed their own teaching manuals. Literature explains that they adopted suggested curriculum materials that come along with the MCE kits.

To the best of the knowledge of the Researcher, not much data has been found yet on the operational use of MCE in West Africa and its effect on the improvement of curricula, conceptual development or the acquisition of as many learning skills. The only documentary data found was on the theoretical adoption of the MCE for use in schools in Cameroon and Senegal (Bell & Bradley, 2012). The impact of the MCE approach on learners in Cameroon and Senegal (if adopted) has not yet been documented. Thus, the adoption and trial of the MCE in a teacher training university in Ghana is novel. The use of the MCE in this study enabled trainees to unearth their prior conceptions of many principles in inorganic chemistry and reconstructed more scientific concepts by themselves through MCE lessons and practical activities. The identification, acknowledgement and reconstruction of knowledge by students are novel teaching methods which were made possible through the use of the MCE by the trainees in this study. Most of the MCE studies done by earlier researchers were on enhancing curriculum development only or enhancing the attitudes of students towards science. However, this study used the MCE in the university setting, among teacher trainees, developed teaching manuals, and helped the trainees to self-construct inorganic chemistry concepts. The findings from this current study showed that the trainees who participated acquired as many as 16 learning skills, and the understanding, as well as application of many chemistry concepts. They were in addition, able to design and develop their own MCE-based teaching materials for use in their future schools. As many as 18 attributes of the MCE, which make it a useful tool for MCE-based lessons and activities, were also identified in this current study. A couple of these have already appeared from the findings of some studies, such as its being simple and fun (Mashita, Norita, & Zurida, 2009; Mafumiko, 2008), useful (Mafumiko, 2008; Abdullah, Mohamed, & Hj Ismail, 2009), useful for deprived communities (Bell & Bradley, 2012; Engida, 2012; Sileshi, 2012) and cost effective (Singh, McGowan, Szafran, & Pike, 2000). None of these researchers identified some of its useful attributes such as the robust nature, availability, flexibility of approach, skills-based learning, effectiveness for large classes, inherent critical nature, and the inherent deductive approach it offers to users. These attributes have been documented for the first time in Ghana, and possibly the whole of Africa, if not the world at large.

In addition to the enormous benefits of the MCE which were unearthed in this study, a 2-tiered test (adapted from Treagust, 2006) was developed for use. The use of tiered test was not found to have accompanied any of the MCE studies to unearth students‟ alternative conception. Neither were they found to have been used in conceptual studies done in Ghana, though they have been employed in other studies in the Western world (Tan, Goh, Chia, & Treagust, 2002; Chou & Chiu, 2004; Treagust, et al., 2010). These authors who employed the use of the 2-tiered test unearthed students‟ alternative concepts on the molecular presentation of chemistry only in Taiwan (Chou & Chiu, 2004), or chemical reactions, using multiple levels of representation (Chandrasegaran, Treagust, & Macerino, 2007), for qualitative analysis (Tan, Goh, Chia, & Treagust, 2002), for evaluating students‟ understanding of kinetic particle theory (Treagust, et al., 2012), and for the evaluation of general misconceptions in science. This study however, went further to develop a two-tiered test, which specifically covered all areas of basic inorganic chemistry which can be useful not only for Ghana, but also for the international community.

Thus, this MCE study has been able to come out with novel ideas, teaching methods, as well as accompanying teaching materials, which have been trialled and found worthy of use by the education community. The MCE activities proved beyond doubt that it was an interactive tool for conceptual enhancement among first year undergraduate chemistry teacher trainees. All these new findings have been documented and could be used or trialled by other educationists. As suggested by Locaylocay (2006) and Hanson and Acquah (2014) science curricula should be designed to encourage formal thought but should be supported with a lot of concrete activities for students to learn from first-hand experience. Through such activities, novel ideas and procedures can emerge to enhance teaching and learning.

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# APPENDICES

**Appendix A: A sample of a diagnostic concept test for basic inorganic chemistry**

Name: ………………… Level ……………… Date ……………..

Attempt all the questions.

1. Sodium reacts slower with water than potassium metal

i) True ii) ) False

*Reason*

a) Sodium metal is smaller and so forms a second layer of water molecules around it , rendering it slow in reacting with water

b) Potassium metal has a heavier mass and so reacts more vigorously with water

c) The bonding in potassium metal is not as „tight „or compact as in sodium metal due to its large size

d) Both sodium and potassium atoms have a valency of one but different size (sodium being smaller). Therefore cohesive forces are stronger in sodium, thereby making it react less vigorously with water.

2. Predict whether aluminium would react faster or slower than magnesium with water.

i) Aluminium ii) Magnesium

*Reason*

a) Aluminium will react faster than magnesium because it has a larger atomic number and more valence electrons

b) Calcium will react faster than aluminium because it is bigger in size and has less valence elections

c) Magnesium will react faster than aluminium. Reactivity of the elements with water increases down the group and decreases across a period. The factors which account for this are size, electronic configuration (valence electron) and nature of species concerned.

d) Aluminium will react faster than Magnesium. Reactivity of the elements with water increases down the group and decreases across a period. The factors which account for this are size, electronic configuration (valence electron) and nature of species concerned.

3. How would you show by experiment that a solution contained both carbonates and sulphate ions?

i) By adding $BaCl_2$ (aq) first ii) HCl (aq) is added first

*Reason*

a) HCl (aq) is added first to neutralize the solution If the white precipitate remains after 5 minutes, then both ions are present as they all cannot dissolve in the acid.

b) $BaCl_2$ (aq) is added first to see if a white precipitate will form. Then HCl (aq) is added if necessary. If a white precipitate persists, then both ions are present

c) HCl (aq) is added first to neutralise the solution, then the barium chloride solution is added. If a carbonate is present no precipitate will form. If a sulphate ion is present a precipitate forms. Then both ions are present.

d) The barium chloride is added first. If a white precipitate forms then the presence of carbonates, sulphates or both is indicated. If HCl (aq) is added as a distinguishing factor and bubbles of gas appear but white precipitate still remains, then it implies both ions are present.

4. How can we test for halide ions in aqueous solutions?

i) By the addition of nitric acid and silver nitrate solutions

ii) By the addition of silver nitrate followed by nitric acid solutions.

*Reason*

a) By the formation of precipitates with distinctive colours upon adding nitric acid and silver nitrate

b) When the acid is added it dispels other nitrates which could possibly form

c) When the acid is added first it dispels other precipitates which could possibly form before the addition of the silver nitrate

d) When the silver nitrate is added first, it enhances the formation of the silver chloride faster and better than when the acid is added

5. Sodium metal spontaneously reacts with water. What sort of reaction does this represent?

   a) Single replacement b) double replacement c) synthesis d) decomposition

   *Reason*

   a) Things have changed about both sodium metal and water

   b) Only sodium metal has had a replacement

   c) Both reacting species have decomposed or been broken up

   d) New species have been formed from raw materials

6. A solution is said to be ……… when more solute can be dissolved at a given temperature

   a) Supersaturated b) saturated c) unsaturated d) concentrated

   *Reason*

   a) A strong solution cannot absorb any more solute

   b) A solution is unsaturated when it changes at different temperature

c) An unsaturated solution has the capacity to allow more solute into its system

d) Supersaturated solutions allow more solute in at given temperatures

7. What would be the mole ratio if the concentrations of lead nitrate and sodium iodide solutions are doubled?

i) It would double ii) It will remain unchanged iii) It would be halved

*Reason*

a) Doubling the volumes of both increases the amount of substance and so the mole ratio doubles

b) Doubling the concentration does not affect the parts from each that react to give a whole new product and so the mole ratio will not change

c) The mole ratio will have to be halved as concentrations have increased so that equal amounts will be found in the product or else the ratio will increase

d) The mole ratio is halved so that Le Chaterlier‟s principle will hold

8. If 5 drops of 0.1 M hydrochloric acid HCl(aq) supplied in a practical session were replaced with 5 drops of 0.1 M sulphuric acid ($H_2SO_4$(aq)) of the same concentration, in moles/dm$^3$, how many drops of 0.10 M sodium hydroxide (NaOH(aq)) solution would be required to reach the end point in this titration ? Explain your answer

i) 5 drops of NaOH (aq) ii) 10 drops of NaOH (aq)

*Reason*

a) 10 drops of 0.10 M NaOH (aq) will be required. This is because sulphuric acid is a diprotic acid whereas hydrochloric acid is a monoprotic acid.

b) 5 drops of each solution would be required since the mole ration has to be 1:1

c) 10 drops of 0.10M Na OH (aq) is required. This is because sulphuric acid is diprotic with a stronger acid strength.

d) If 5 drops of 0.10M NaOH (aq) is being used, then half the acid strength must be used so the reacting ration will be one part of base to two parts of acid since the acid is diprotic.

9. What is the first thing to do when solving a stoichiometric problem?

a) Find the limiting reactant c) Write a balanced chemical equation

b) Find the excess reactant d) find the empirical formula

*Reason*

a) The limiting reactant enables you to do away with what is not required as is done with spectator ions

b) A balanced equation gives the ratio between the reacting substances

c) An empirical formula gives an idea about the species involved in the reaction and what their proportions truly are. The same proportions will be translated in ascending or descending order

d) Equivalent amounts of reacting species have to be worked out first

10. When chemical substances such as hydrochloric acid react with sodium hydroxide solution, there is often a temperature change

i) True ii) False

*Reason*

a) Temperature change occurs only when solutions are concentrated and have to struggle to break bonds

b) Chemical reactions occur when concentrations are about the same

c) Temperature change occurs only when solutions are strong and must re-arrange themselves by breaking and forming bonds

d) Breaking and forming of bonds within the reactants results in decrease or increase of energy of the system.

11. Would there be a change in temperature when different volumes of reacting species of the same concentration are used in an experiment?

i) Yes ii) No

*Reason*

a) Different volumes of reactants result in different amounts of the products being formed

b) Different volumes of the same reactants have the same the same temperatures so no change is expected

c) Resulting products from the same reactant, despite their volumes, have the same products so should not have different temperatures

d) The same volume of reacting species of the same concentration used in an experiment also have varying temperatures because different products can be formed

12. The $SO_3$ molecule is non- polar.

i) True ii) False

*Reason*

a) It has a symmetrical arrangement of oxygen atoms about the central sulphur atom

b) The oxygen atoms draw the sulphur atom to themselves and cause a linear shape to result

c) The sulphur atom repulses the oxygen atoms

d) The oxygen atoms donate electrons to the sulphur atom

13. The N-N-O molecule is non-polar.

i) True ii) False

*Reason*

a) The N-N bond is non-polar and so gives the molecule N-N-O its characteristic shape

b) The N-O bond is non-polar. It gives the molecule a non-polar nature

c) The polarity of N-O overrides the N-N bond so there will be no polarity

d) The $SO_3$ molecule exhibits the neutral non-polar state

14. A sodium ion is only bonded to the chloride ion it donates its electrons to.

i) True ii) False

*Reason*

a) Each positive ion is bonded only to the negative ion that gave it an electron

b) Each positive ion is bonded to each of the neighbouring negative chloride counter ions

c) A positive ion is always attracted to a negative ion

d) A chlorine atom can only form one strong ionic bond because it can only accept one more electron in its outer shell

15. A positive ion can be bonded to any neighbouring negative ion, if it is close enough.

i) True ii) False

*Reason*

a) The bond is just the attraction between the oppositely charged ions. If the ions are close together, the resulting force will be a very strong one
b) Close enough ions tend to repulse each other as electrons like to be free. Thus neighbouring ions cannot form bonds arbitrarily
c) The reason a bond is formed between chloride ions and sodium ions is because an electron has been transferred between them
d) A negative ion can only be attracted to one negative ion

16. Each proton in a nucleus attracts one electron

i) True ii) False

*Reason*

a) All the protons in the nucleus attract all the electrons and vice versa
b) The nucleus is not attracted to the electrons
c) If the outermost electron is removed, one proton remains open to reaction
d) Electrons act a one force and revolve round the protons and attracts them

17. The force pulling the outermost electron towards the nucleus is greater than the force pulling the nucleus towards the outermost electron.

i) True ii) False

*Reason*

a) If the outermost electron is removed from an atom, it will not return to exert a force because there will be a stable electronic configuration
b) There is no such force as electrons pulling on the nucleus

c) Electrons are always attracted to the core of the atom. Thus the inner pulling force is greater than that which pulls the nucleus outward

d) Both experience the same magnitude force

18. After a sodium atom is ionized, it requires more energy to remove a second electron because the second electron is in a lower energy level.

i) True ii) False

*Reason*

a) The outermost electron is 3S electron the next electron is a 2p electron, which is at a lower energy and shielded less .It is more attracted

b) The next electron will be in a higher energy level

c) It is always difficult to remove a second electron from an atom. More energy is always required

d) Second ionization energies are always high.

19. How many molecules of ammonia would be present in 34.0g of ammonia? (Avogadro‟s number, N = $6.022 \times 10^{23}$)

*a)* $1.77 \times 10^{22}$ b) $6.02 \times 10^{23}$ c) 34 d) $1.20 \times 10^{24}$

*Reason*

a) 34 g of ammonia was used and so the molecules will be 34 accordingly

b) The answer is $1.20 \times 10^{24}$ because one mole of ammonia is equal to 6.02 $\times 10^{23}$. Thus 2 moles will be the answer stated

c) One mole of an entity is equivalent to $6.02 \times 10^{23}$

d) Ammonia weighs 17g and so $1.77 \times 10^{22}$ would be its equivalent molecules by translation

20. If the concentration of a weak acid is significantly high, then it can dissociate adequately in solution.

i) True ii) False

*Reason*

a) This is because it will have a relatively large amount of solute dissolved in a solvent

b) In a weak acid only a proportion of the molecules dissociate to give hydrated hydrogen ions and anions in solution

c) In the now strong solution, all of the molecules will dissociate to give hydrated hydrogen and anions in solution

d) Strong solutions of weak acids dissociate just like strong acids

21. A concentrated acid has a relatively large amount of solute dissolved in the solvent.

i) True ii) False

*Reason*

a) In such a solution the amount of solute particles with respect to the solvent particles is always high

b) In such a solution all of the molecules dissociate to give hydrated hydrogen ions and anions in solution

c) Only a proportion of molecules are able to dissociate in such solutions as there would be a strong bond between the many molecules; then it would be a concentrated acid

d) This is because there would be solvated ions present but no associated molecules present

22. Lithium is expected to have a higher melting point than sodium. Could this be with Lithium‟s smaller size?

i) True ii) False

*Reason*

a) Incidentally the cations of lithium tend to move slower in aqueous solutions than sodium cations when involved in chemical reactions

b) The lithium metal is smaller than the sodium metal and so less energy is required in disrupting its metallic lattice

c) More energy is required to disrupt the metallic lattice in lithium as it has stronger bonds

d) Sodium has more particles than lithium has. Therefore disrupting the sodium particles in its lattice will require more energy than would be expected for lithium.

23. HF (aq) is expected to be a stronger acid than HCl (aq).

i) True ii) False

*Reason*

a) The sizes of hydrogen and fluorine are compatible and so a strong bond will formed between them and result in a very strong acid

b) The hydrogen bonding between fluorine and hydrogen will be relatively stronger than that between hydrogen and a slightly bigger chlorine atom. Thus the acid strength in HCl will be lower as compared to HF

c) The F-F bond in fluorine is weaker than the Cl-Cl bond in chlorine. This enhances the HF bond in fluorine and so makes it a stronger acid

d) The H-Cl bond is weaker than the H-F bond. Thus H-Cl dissociates with greater ease to release its $H^+$ (aq) into solution with greater ease than can occur in the HF molecule.

In the following questions, you will be required to make a choice by placing a tick (√) against a statement you think is correct, and then justify the choice you have made in the space provided.

24. □ $Cl^{7+}$ is more stable than $Cl^-$ ……………………………………………..

□ Cl and $Cl^-$ are equally stable ……………………………………………..

□ Cl is less stable than $Cl^-$ ……………………………………………..

□ I do not know ……………………………………………………………..

I make this choice because ……………………………………………

25. □ $Be^{2+}$ is more stable than Be …………………………………………

□ $Be^{2+}$ and Be are equally stable ……………………………………

□ $Be^{2+}$ is less stable than Be ……………………………………………..

□ I do not know ……………………………………………………

I make this choice because ……………………………………………

26. □ A sodium atom is more reactive than a sodium ion …………………

□ A sodium ion is more reactive than a sodium atom …………………..

□A sodium ion and sodium atom are equally reactive …………………..

□ I do not know …………………………………………….....................

I make this choice because ……………………………………………

In this section, read the statement and choose whether a definition is correct or wrong. Decide if the definition is helpful and state why you made that choice.

27. An element is a substance which cannot be split up into simpler substances. Is the definition correct? Would it help someone to understand?

□ Yes □ No, it is wrong □ I am not sure

I make this choice because ………………………………………………….

28. A compound is made up of two elements mixed together. Is this definition correct? Would this definition help someone else?

□ Yes □ No, it is wrong □ I am not sure

I make this choice because …………………………………………………

29. An atom is the smallest particle of an element that still shows the chemical properties of the element. Is the definition correct? Is it helpful?

□ Yes □ No, it is wrong □ I am not sure

I make this choice because …………………………………………………

30. A molecule is a group of two or more atoms bonded together. A molecule of an element consists of one or more similar atoms; a molecule of a compound consists of two or more different atoms bonded together.

Is this definition correct? Is it helpful to someone else?

□ Yes □ No, it is wrong □ I am not sure

I make this choice because …………………………………………………

31. In a chemical equation, the number written in front of the chemical substance is……

a) Reactant b. product c. multiple d. coefficient

*Reason*

a) The number differentiates between reactants and products

b) The number tells the various proportions of chemicals required by equivalent amounts

c) The number tells the simple ratios when concentration increases in reactions

In this last section, you are given a word equation and an equation using chemical symbols. You should try to classify each type of reaction as displacement, neutralisation, oxidation, reduction, thermal decomposition or none of the above with reasons. Use a tick to describe the type of reaction. Hint: Some could be equations of more than one type.

32. Nitrogen + Hydrogen → Ammonia

$N_2 (g) + 3H_2 (g) \rightarrow 2NH_3 (g)$

Type of reaction

□ Displacement

□ Neutralisation

□ Oxidation

□ Reduction

□ Thermal decomposition

□ None of the above

I make this choice because

…………………………………………………………..

33. Zinc + Copper sulphate → Zinc sulphate + Copper

$Zn\ (s) + CuSO_4\ (aq) \rightarrow ZnSO_4\ (aq) + Cu\ (s)$

Type of reaction

□ Displacement

□ Neutralisation

□ Oxidation

□ Reduction

□ Thermal decomposition

□ None of the above

I make this choice because

…………………………………………………………

34. Sodium Hydroxide + Nitric acid → Sodium nitrate + Water

$NaOH\ (aq) + HNO_3\ (aq) \rightarrow NaNO_3\ (aq) + H_2O$

Type of reaction

□ Displacement

□ Neutralisation

□ Oxidation

□ Reduction

□ Thermal decomposition

□ None of the above

I make this choice because

…………………………………………………………..

**Appendix B: Observation check list**

Group Name/ Number …………Level …………… Date ……………………

Number of students in the class: ………… Number of students in a group: …

Observe individual students and / or a group of students for about a minute and record your observation. Use the symbol (+) to indicate a positive behaviour or response as indicated on the profile, the symbol (±) to indicate a behaviour or activity that was partially observed or executed by student/group and the symbol (-) to indicate that a required behaviour/ activity was not executed or followed.

| Expected student behaviour/Activity/ Response | (+) A | (±) B | (-) C |
|---|---|---|---|
| 1. Students relate prior knowledge to the day"s lesson | | | |
| 2. Students contribute to pre-lab discussions and connect it to the day"s activity | | | |
| 3. Students form groups to begin work and show acquisition of skills | | | |
| 4. Student-student cooperation evident | | | |
| 5. Students/groups interact with teacher as expected | | | |
| 6. Students show evidence of reading with understanding | | | |
| 7. Students show evidence of skill acquisition by working with apparatus and materials | | | |
| 8. Materials obtained and activities started without delay | | | |
| 9. Students discuss their outcomes in small groups | | | |
| 10. Students show understanding and interest in the lab procedures and activities they are doing | | | |
| 11. Students demonstrate acquisition of process and concept skills | | | |
| 12. Students are able to work within the allotted time | | | |
| 13. Students are able to relate the activities with theory | | | |
| 14. Students use the required concept terms and language with comprehension | | | |
| 15. Students do a recap to confirm understanding of concept | | | |
| 16. Students relate the newly learned/ reinforced concept in other situations to demonstrate permanent learning | | | |

NB: A similar observation sheet was used for theory lessons.

**Appendix C: Microscale chemistry activity survey sheet for teacher trainees**

**(QUESTIONNAIRE)**

This evaluation sheet is to assess your candid impressions about the use of micro scale chemistry equipment (MCE). It consists of three (3) parts: sections A, B and C. Do not write your name, level or any identity for that matter on this sheet. Do not discuss your choices with your colleagues. Try to work independently. Your views will be treated as confidential.

**Section A**

This section comprises statements about your views on the Micro Chemistry Equipment (MCE) approach. It also assesses your reaction to the use of MCE in terms of your ability to understand and use scientific concepts as well as how you learn. You may agree or disagree with some of the written statements. Read each one carefully and record your reaction by making a tick (√) in a box that describes your position on the statement. The scale / ratings for choices you wish to make have been explained below.

SD = Strongly Disagree (1 point) D= Disagree (2) N = Not sure (3) A= Agree (4) SA= Strongly Agree (5)

| | 1 SD | 2 D | 3 N | 4 A | 5 SA |
|---|---|---|---|---|---|
| 1.The activities done in class were linked to topics discussed | | | | | |
| 2.The use of MCE was very helpful in my understanding of concepts | | | | | |
| 3.The outlined practical activities and my understanding of concepts helped me to prepare better for other related topics | | | | | |
| 4.The use of MCE enhanced the way I think critically | | | | | |
| 5.The use of MCE made me feel like exploring my understanding of other topics, still using the MCE easily | | | | | |
| 6.The use of MCE has equipped me with skills and confidence in planning other basic easy activities on my own | | | | | |
| 7.It has exposed me to easier ways of conducting chemistry experiments | | | | | |
| 8.It afforded me the needed opportunity to use materials and equipment | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| 9.MCE increased student-student cooperation in the classroom | | | | | |
| 10.MCE increased student-teacher cooperation in the classroom | | | | | |
| 11.Cooperation in class enhanced my conceptual understanding of chemical principles | | | | | |
| 12.My sense of responsibility in taking charge of equipment has been affected positively since the use of the MCE | | | | | |
| 13.My sense of responsibility has not been affected in any way at all. | | | | | |
| 14.MCE helped me to develop a better conceptual understanding about Quantitative analysis | | | | | |
| 15.MCE helped me to gain a better conceptual understanding about Qualitative analysis | | | | | |
| 16.MCE helped me to understand the Mole concept | | | | | |
| 17.The MCE helped me to understand the Stoichiometry concept better | | | | | |
| 18.The use of MCE helped me to have a better conceptual understanding of how to balance chemical equations | | | | | |
| 19.The use of MCE helped me to understand more about Acid-base concepts and reactions | | | | | |
| 20.The use of MCE helped me to understand more about the pH concept | | | | | |
| 21.The use of MCE helped me to have a better understanding about writing Net ionic equations | | | | | |

**Section B:**

**This section consists of six (6) statements requesting your opinion about how much you liked or disliked the MCE activities. Read each item and give a candid opinion about it.**

1. List two (2) things that you liked most in the MCE activities with reasons. ……………………………………………………………………………………

2. List two (2) things that you disliked about the MCE activities, with reasons ……………………………………………………………………………………

3. In what respects were these lessons different from your regular chemistry lessons?

   ……………………………………………………………………………………

4. Write down at least three (3) important things that you learned from the MCE activities.

   ……………………………………………………………………………………

5. In your own view, how would the use of MCE be in teaching and doing chemistry activities be beneficial in our basic and senior high schools?

   ……………………………………………………………………………………

6. Which learning concept did the MCE approach help you to understand best?

   ……………………………………………………………………………………

7. Suggest with reasons, whether you would recommend the adoption of the MCE approach in lessons/courses at UEW and hereafter.

   ..............................................................................................................................

8. Please write down any general comments that you have about the use of MCE.

   ……………………………………………………………………………………

**Section C**

**This section assesses the usefulness of the MCE practical approach. Read each statement carefully and tick in an appropriate rating box, your opinion on the usefulness of the MCE approach.**

Scale to use is 1=Not helpful 2=slighyly helpful 3=moderately helpful 4= helpful 5=very helpful

| How useful did you find these activities in helping you to learn chemistry? | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Effect of doing pre-lab discussions | | | | | |
| Influence of post-lab discussions | | | | | |
| Analysing and explaining experimental results | | | | | |
| Doing the recall questions in the pre-lab | | | | | |
| Doing the experiment and seeing the outcome personally | | | | | |
| Predicting what will happen in a given activity | | | | | |
| Preparing solutions on your own | | | | | |
| In relating the already or yet to be learned theory to practice | | | | | |

**Appendix D: Teacher trainees' semi-structured interview scheme**

1. What impressions do you have about the MCE approach and lessons?
2. What did you like best?
3. What did you like least?
4. How different is this new approach (MCE) different from the traditional approach that you are used to?
5. How do you rate the interaction between you and your teacher with respect to this MCE approach?
6. Did the MCE lessons and activities in any way affect the way you understand concepts? How?
7. Would you say that the MCE lessons and activities broadened your cognitive processes so that you could identify your former unscientific or wrong scientific beliefs that you and your friends raised?
8. Did you see the MCE approach as shifting focus from teaching to learning?
9. Was time allotted for the various activities adequate? Was the MCE approach time consuming?
10. Do you have any suggestions to make on the improvement of the MCE approach?

**Appendix E: MCE Teaching manual (A curriculum material for teachers)**

Part 1: Explanation to the teacher

1. Introduction

This lesson is designed for the course, *Introduction to Inorganic Chemistry*. The content of this material covers the concept of stoichiometry, mole ratio, balancing of chemical equations to determine concentration, reactions of metals with water and tests for ions in aqueous solutions. In short it covers issues on analytical chemistry – quantitative and qualitative analysis. Thus, what is contained in this curriculum material would be applicable at the University as well as in the Senior and Junior High Schools to reach both general science and elective chemistry.

2. Micro Chemistry Equipment

Micro Chemistry refers to practical chemistry carried out on a reduced scale, using small quantities of chemicals within the range of 0.001-1.00 g or ml of substances. The work equipment are simple plastic materials. The main focus in designing activities with this equipment has been on introducing microscale chemistry practical activities as a means to promote active learning in the chemistry classroom as well as to reduce cost for conducting practical activities in schools.

Since experiments based on this approach are new, students may require time to get used to some of the techniques in this first activity. They may have to master the skill of taking and adding minute quantities of chemicals such as methyl orange, water and others to test chemicals. Nevertheless, due to the small quantities or volumes of chemicals used, they can always quickly correct their mistakes and still achieve the required results in relatively shorter periods of time than they otherwise would have with standard equipment.

The emphasis in this new microscale chemistry approach is on careful observation and personal interpretation of procedures. Students must get the opportunity to experience what happens and think about why it happens as it does.

3. Teacher support materials

Included in your lesson material is the student worksheet which has been prepared to guide students in performing experiments on the micro chemistry equipment approach with cognitive develop as the underlying goal. Besides, you are provided with suggested scientific answers to guide in in scoring students" work.

4. Sequence and content of lessons

| Lesson | Lesson content | Time & period(Minutes) |
|---|---|---|
| 1 | Acid-base indicators | 20 |
| 2 | Introduction to acid-base titration | 30 |
| 3 | Determining the concentration of an acid | 30 |
| 4 | Stoichiometry of a precipitation reaction | 25 |
| 5 | Reactions of metals with water | 20 |
| 6 | Reactivity of Group 17 elements | 30 |
| 7 | Testing for ions in aqueous solutions | 30 |

The lessons have been planned to fit into the time allotted for practical work.

5. General issues on preparation and execution of lessons

For a successful practical activity

- List all the equipment required for each group and multiply by the number of groups so as to get the actual quantity required for that particular activity. Do the same for the chemicals required.

- Try out all the experiments to make sure that results will be achieved when students carry out the activity also.
- Anticipate and write down all possible problems that students may encounter for each activity and find possible solutions or help to give. Some of these could be with identification of colour changes, the identification of precipitates and manipulation of some basic equipment.
- Work out how you will quickly distribute equipment and chemicals to facilitate your work.
- Group students and assign roles to ensure effective collaboration
- Supervise effectively by moving round the work groups to ensure safety rules are being observed and offer any assistance students may require
- Ensure students clean the plastic equipment with lots of water to prevent discolouration and disfigurement of equipment. Used chemicals should be disposed of correctly while all unused chemicals are returned to you, the teacher.

6. How to consolidate lesson outcomes

- Students should be encouraged to reflect on practical activities as a post-lab exercise
- Assign extension (follow-up) questions on principles studied

*Explain to learners that such activities are analytical experiments, and that analytical methods depend on sample sizes. Thus, using MCE, means using micro measures, and micro methods. Introduce macro, semi micro, ultra-micro and sub microgram measurements, methods and corresponding scales for the measurements (Christian, 2004).

## Appendix F: MCE teaching manual (Final version of a lesson material -2)

1. Introduction

Today, we will move into the world of micro scale chemistry. The micro scale chemistry approach is simply practising chemistry with small quantities of chemicals and equipment. They are simple, yet clear and east-to-do experiments which will give you more insight into quantitative, qualitative and analytical issues in chemistry. It will also help you to master a lot of useful practical skills

In this particular experiment, you will learn how to determine the volume of sodium hydroxide solution that would be required to titrate equal volumes of two unknown acids with known concentrations

Focus question:

What volume of sodium hydroxide solution is required to titrate equal volumes of two different acids of the same concentration?

Objective:

By the end of the lesson, students should be able to

a) Manipulate the micro chemistry equipment and work with small quantities of chemicals with precision

b) Use volumes of given solutions A and B against aqueous sodium hydroxide to determine the mole ratio of reacting substances

c) Predict with logical reasoning, the mole ratio of reacting species if the volume of aqueous sodium hydroxide to a given acid is three times that of the acid and again if the volume of aqueous sodium hydroxide is only half that of the acid.

2. Resources, materials and further reading (if any)

The RADMASTE Micro Chemistry Equipment Manual for Teachers and accompanying student worksheets (Basic)

| Apparatus | Chemicals |
|---|---|
| 1 Comboplate | Acid A [0.10M] |
| 1 Micro spatula | Acid B [0.10M] |
| 3 Propettes | NaOH(aq) [0.10M] |
| | Methyl orange indicator |

*CAUTION: If any chemical spills on your skin, rinse the affected part with plenty of cold water. Avoid breathing vapour from given chemicals.

3. Lesson plan and timing (in minutes)

| Time (Minutes) | Student activity | Teacher"s role |
|---|---|---|
| 5 | Concept test/Pre-lab discussion | Unearth students" naïve concepts, if any |
| 10 | Grouping and assigning of roles | Ensure each student has an assigned role |
| 30 | Student activities | Monitor group activities. Record important incidents. Provide support |
| 10 | Post-lab | Lead discussion on students" reports Recap and correct unscientific ideas (if any) |
| 5 | Clean up. Apparatus and unused chemicals returned. Homework based on chemical concept assigned | Ensure all waste solutions are disposed off into waste bottle while unused ones are returned |

4. Main Lesson

Procedure and observations

i) Get your comboplate ready. Add 5 drops of tap water into well A[1] with a propette

ii) Add one drop of methyl orange indicator into well A [1]. Note the colour of the solution

iii) Repeat steps i and ii above in wells A[2] and A[3]using acid A instead of tap water

iv) Add sufficient drops of NaOH (aq) to well A [2] so that the colour will turn to be the same as for A[1].

How many drops were added? A [2]… A [3]: ……. Average: …..

Q1. What is the volume/ ratio of aqueous sodium hydroxide to Acid A?

v) Repeat steps iii and iv in wells A [4] and A [5] but use B now instead of acid A. How many drops of aqueous sodium hydroxide did you add?

A [4]: ………… A [5]:……… Average: ………

Q2. What is the volume ratio of NaOH (aq) to Acid B?

Q3. From your outcomes, what is the answer to the focus question above?

Q4. What can you conclude about Acids A and B? Give possible molecular formulae for Acids A and B

Q5. Write and balance equations for the proposed reactions between the sodium hydroxide solution and acids A and B.

Q6a. Find the amount of substance contained in $25cm^3$ of 0.10M NaOH (aq).

b. What would be the amount of substance contained in $25cm^3$ of 0.10M Acid B?

Q7a. Explain the terms precision and accuracy.

b. Are the volumes of base used precise or accurate? Explain

Q8. If the average number of drops of base required to titrate 6 drops of acid A was experimentally determined to be 8 while the true value should have been exactly 6, would the experimentally determined results be imprecise or accurate?

Conclusion

The conclusion must be derived from the analogies and discussions of experimental results. Expected answers are shown in bold print.

Assignment

The assigned work is to consolidate the new principle or concept studied

Analysis and discussion

The introduction began with an activity that students are already familiar with.

**Appendix G: Teaching manual (An MCE student's worksheet)**

Experiment 2: Determination of mole ratios through volumes of solutions

Introduction

Today, you will begin to explore the world of micro scale chemistry. Microscale chemistry is that branched science which deals with small-sized plastic equipment that requires the use of very small quantities of chemicals. The smaller volumes of chemicals used enhance the achievement of end results of activities in relatively shorter periods as compared to the traditional work periods with complex standard macro equipment. In effect, a lot of extra time is obtained when one works with micro equipment. The extra time at one‟s disposal could be used for extensive discussions of the actual chemical principles underlying the practical activities. The use of micro chemistry equipment also enhances your acquisition of practical skills since each one of you engages in the manipulation of the simple equipment and learns to use it accurately to achieve positive results. In this experiment you are going to determine the volumes of aqueous sodium hydroxide that are required to titrate equal volumes of two unknown acids with known concentrations.

Focus question:

What volume of sodium hydroxide solution is required to titrate equal volumes of two different acids of the same concentration (0.10M)?

1. Requirements: Resource materials and further reading (if any)

   The RADMASTE Micro Chemistry Equipment Manual for Teachers and accompanying student worksheets (Basic)

| Apparatus | Chemicals |
|---|---|
| 1 Comboplate | Acid A [0.10M] |
| 1 Micro spatula | Acid B [0.10M] |
| 3 Propettes | NaOH(aq) [0.10M] |
| | Methyl orange indicator |

*CAUTION: If any chemical spills on your skin, rinse the affected part with plenty of cold water. Avoid breathing vapour from given chemicals.

2. Procedure:

Procedure and observations

i) Get your comboplate ready. Add 5 drops of tap water into well A[1] with a propette

ii) Add one drop of methyl orange indicator into well A [1]. Note the colour of the solution

iii) Repeat steps i and ii above in wells A[2] and A[3] using acid A instead of water

iv) Add sufficient drops of NaOH (aq) to well [A]2 so that the colour will turn to be the same as for A[1].

How many drops were added? A [2]… A [3]: … Average: …

Q1. What is the volume/ Ratio of aqueous sodium hydroxide to Acid A?

v) Repeat steps iii and iv in wells A [4] and A [5] but use B now instead of acid A. How many drops of aqueous sodium hydroxide did you add?

A [4]: ……… A [5]:……… Average: ………

Q2. What is the volume ratio of NaOH (aq) / Acid B?

Q3. From your outcomes, what is the answer to the focus question above?

Q4. What can you conclude about Acids A and B? Give possible molecular formulae for Acids A and B

Q5. Write and balance equations for the proposed reactions between the sodium hydroxide solution and acids A and B.

Q6a. Find the amount of substance contained in $25cm^3$ of 0.10M NaOH (aq).

b. What would be the amount of substance contained in $25cm^3$ of 0.10M Acid B, if it should react with $25cm^3$ of 0.10M NaOH (aq)?

Q7a. Explain the terms precision and accuracy.

b. Are the volumes of base used precise or accurate? Explain

Q8. If the average number of drops of base required to titrate 6 drops of acid A was experimentally determined to be 8 while the true value should have been exactly 6, would the experimentally determined results be imprecise or accurate?

Conclusion

The conclusion must be derived from the analogies and discussions of experimental results. Expected answers are shown in bold print.

Assignment

The assigned work is to consolidate the new principle or concept studied

**Appendix H:Teaching manual (A teacher's manual with suggested answers)**

Experiment 2: Determination of mole ratios through volumes of solutions

Introduction

Today, you will begin to explore the world of micro scale chemistry. Microscale chemistry is that branch of science which deals with often times, small-sized plastic equipment that requires the use of very small quantities of chemicals. The smaller volumes of chemicals used enhance the achievement of end results of activities in relatively shorter periods compared to the traditional work periods with complex standard macro equipment. In effect, a lot of extra time is obtained when one works with micro equipment. The extra time at one‟s disposal could be used for extensive discussion of the actual chemical principles underlying the practical activities. The use of micro chemistry equipment also enhances your acquisition of practical skills since each one of you engages in the manipulation of the simple equipment and learns to use it accurately to achieve positive results. In this experiment you are going to determine the volumes of aqueous sodium hydroxide that are required to titrate equal volumes of two unknown acids with known concentrations.

Focus question:

What volume of sodium hydroxide solution is required to titrate equal volumes of two different acids of the same concentration?

2. Requirements: Resource materials and further reading (if any)

   The RADMASTE Micro Chemistry Equipment Manual for Teachers and accompanying student worksheets (Basic)

| Apparatus | Chemicals |
|---|---|
| 1 Comboplate | Acid A [0.10M] |
| 1 Micro spatula | Acid B [0.10M] |
| 3 Propettes | NaOH(aq) [0.10M] |
| | Methyl orange indicator |

*CAUTION: If any chemical spills on your skin, rinse the affected part with plenty of cold water. Avoid breathing vapour from given chemicals.

2. Procedure:

Procedure and observations

i) Get your comboplate ready. Add 5 drops of tap water into well A[1] with a propette

ii) Add one drop of methyl orange indicator into well A [1]. Note the colour of the solution. **Yellow/ Orange colour**

iii) Repeat steps i and ii above in wells A[2] and A[3]. Use acid A instead of water and note the colour. **Red colour results**

iv) Add sufficient drops of NaOH (aq) to well [A] 2 so that the colour will turn to be the same as for A [1].

How many drops were added? A [2]…**5** A [3]: …**5** Average: …**5**

Q1. What is the volume/ Ratio of aqueous sodium hydroxide to Acid A?

**The proportion of NaOH/ acid A is 1:1**

v) Repeat steps iii and iv in wells A [4] and A [5] but use B now instead of acid A. How many drops of aqueous sodium hydroxide did you add?

A [4]:,,,,10,, , A[5]:…10… Average: ……10…

Q2. What is the volume ratio of NaOH (aq) / Acid B?

**The proportion of NaOH/Acid B is 2:1**

Q3. From your outcomes, what is the answer to the focus question above?

**5 drops of the 0.10M of sodium hydroxide solution was required to titrate acid A while 10 drops was required to titrate Acid B**

Q4. What can you conclude about Acids A and B? Give possible molecular formulae for Acids A and B

**Two portions of the sodium hydroxide solution were required to titrate Acid B, even though the volume and concentration of Acid B was the same as for Acid B. The implication here is that every molecule of Acid A is a source of one proton or hydrogen ion while a molecule of Acid B is a source of two protons or hydrogen ions.**

**An example of acid A could be HX as in HCl or $HNO_3$ while acid B could be $H_2X$ as in $H_2SO_4$**

Q5. Write and balance equations for the proposed reactions between the sodium hydroxide solution and acids A and B.

$$HCl + NaOH \rightarrow NaCl + H_2O$$

$$H_2SO_4 + NaOH \rightarrow Na_2SO_4 + 2H_2O$$

Q6a. Find the amount of substance contained in $25cm^3$ of 0.10M NaOH (aq).

**$2.5 \times 10^{-3}$ moles of NaOH (aq)**

b. What would be the amount of substance contained in $25cm^3$ of 0.10M Acid B, if it should react with $25cm^3$ of 0.10M NaOH (aq)?

**It would be double the amount of substance in Acid A or $25cm^3$ NaOH (aq)**

**That is 25cm$^3$ of Acid B would contain 5.0 X 10$^{-3}$ moles of Acid B**

Q7a. Explain the terms precision and accuracy.

Precision is the art of measuring a result in the same range. The result may not be that of a standard but once the same result is constantly obtained one would say the results are precise.

**Accuracy is when a measure is the same or close to a true value.**

b. Are the volumes of base used precise or accurate? Explain

**Since the true volumes of Acids A and B have not been given, the accuracy of the results cannot be determined. The volumes could be said to be precise as for 2 or 3 times the same number of drops were used. The volumes are therefore precise.**

Q8. If the average number of drops of base required to titrate 6 drops of acid A was experimentally determined to be 8 while the true value should have been exactly 6, would the experimentally determined results be imprecise or accurate?

**The experimentally determined result will be inaccurate. It is 33% higher than the true value. If all three drops had been 8 drops, then the values would be precise but still inaccurate as the true value is 6 and not 8.**

(Expected answers are shown in bold print)

**Conclusion**

The conclusion must be derived from the analogies and discussions of experimental results.

**Appendix I: Some identified alternative concepts from the pre-multiple choice test**

| **Areas of identified alternative concepts** | **Trainees with acceptable responses (%)** | **Trainees with wrong or no responses (%)** |
|---|---|---|
| Acid-base reactions and strength<br>Strengths of acids with more than one replaceable hydrogen<br>A strong solution contains more of an acid than a weak one<br>Relationship between quantity of acid or base and its strength<br>Relationship between concentration of acid or base and strength<br>Relationship between weak acid or base and dilution | 23<br>(47.92%) | 25<br>(52.08%) |
| Periodicity<br>Reaction of metals with water<br>Trends across and below periodic table<br>Explanations of anomalies<br>Chemical reactivity, bonding and stability of compounds<br>Periodic parameters<br>Analysis of ions | 22<br>(45.83%) | 26<br>(54.17%) |
| *Chemical bonds*<br>*Bonds have energy between them from the atoms concerned*<br>*Breaking chemical bonds releases the energy*<br>*Ionic bonds are stronger than covalent bonds and difficult to break*<br>*Electron configuration determines number of chemical bonds* | *38*<br>*(79.17%)* | *10*<br>*(20.83%)* |
| Equations, mole, stoichiometry<br>Comparing reaction coefficients<br>Definition of mole<br>Confusion about treating mole as a number or quantity of matter<br>Use of ratio and proportional reasoning for molar problems<br>Increasing amount of reactant and effect on concentration<br>Increasing concentration and effect on mole ratio | 22<br>(45.83%) | 26<br>(54.17%) |
| pH<br>Equating pH to concentration | 25<br>(52.08%) | 23<br>(47.92%) |
| Particulate nature of matter<br>*Definition of atom, element, compound* | *32*<br>*(66.67%)* | 16<br>(33.33%) |
| Hybridisation<br>Concept of „mixing" up of atoms confused with mixing up of atoms | 21<br>(43.74%) | 27<br>(56.26%) |
| Solubility<br>Poor concept of solutions and solubility rules | 19<br>(39.58%) | 29<br>960.42%) |

**Appendix J: Alternative concepts identified in the pre-two-tiered test**

| Identified alternative concepts | Trainees with acceptable responses | Trainees with wrong or no responses |
|---|---|---|
| **Acid-base strength and reactions** | 16 | 32 |
| Strong acids corrode faster than weak acids | (33.33%) | (66.67%) |
| Strong solutions contain more acid than a weak one | | |
| The quantity of an acid or base determines its strength | | |
| A concentrated acid or base is one which is strong | | |
| A weak acid or base is one which is dilute | | |
| Acids with many replaceable types of hydrogen are stronger than those with only one; therefore $CH_3COOH$ must be a stronger acid than HCl, $HNO_3$ and even $H_2SO_4$. | | |
| Strong acids corrode faster than weak acids | | |
| Strong solutions contain more acid than a weak one. They have more reacting ability because they are strong. | | |
| The quantity of an acid or base determines its strength. | | |
| The „molarity‟ of an acid/base can determine its strength | | |
| An acid dissociation constant, Ka of $7.2 \times 10^{-11}$ is bigger than one with a value of $3.4 \times 10^{-8}$ (confusion over integers) | | |
| A concentrated acid or base is one which is „strong‟. | | |
| Such „strong‟ solutions react very fast but the weak one is the one which reacts slowly. (Misconception about concentration) | | |
| A weak acid or base is one which is dilute (misuse of the terms „weak‟ and „dilute‟) | | |
| Salts formed from neutralisation reactions are neutral and so yield neutral solutions | | |
| **Periodicity** | 12 | 36 |
| Nature of elements | (25%) | (75%) |
| Reaction of metals with water | | |
| Trends across and below | | |
| Explanations on anomalies | | |
| Chemical reactivity, bonding and stability of compounds | | |
| Periodic parameters | | |

| | | |
|---|---|---|
| Analysis of ions | | |
| Nature of elements were assumed to be of various sizes and colours but not with respect to composition | | |
| Reaction of metals with water: they said that some would dissolve (as if they were salts) while others (such as metals) would merely remain as if they were inert in solutions | | |
| Reaction of metals with other chemical species such as acids: Metal species in acid solutions would all „burn‟ or „corrode‟. | | |
| The progressive parametric trends across the periodic table and below (group trends) were not easily detected nor could they be appreciated when pointed out to them. For example, the idea of acid strength with respect to metal cations, or size required the understanding of such changes in parameters. Yet, inadequate knowledge made the trainees to assume wrongly that acidity of metal cations would decrease across the periodic table. | | |
| Explanations on anomalies | | |
| Chemical reactivity, bonding and stability of compounds | | |
| Periodic parameters | | |
| Analysis of ions | | |
| ***Chemical bonds*** | *20* | *28* |
| *Bonds have energy between them from the atoms concerned* | *(41.67%)* | *(58.33%)* |
| *Breaking chemical bonds releases the energy* | | |
| *Ionic bonds are stronger than covalent bonds and difficult to break* | | |
| *Electron configuration determines number of chemical bonds* | | |
| Bonds have energy between them from the atoms concerned | | |
| Breaking chemical bonds releases the energy | | |
| Ionic bonds are stronger than covalent bonds and difficult to break | | |
| Electron configuration determines number of chemical bonds between atoms | | |
| During boiling heat energy is absorbed to overcome weak covalent bonds between atoms | | |
| During boiling heat energy is absorbed to overcome weak intermolecular forces between molecules ( confusion about inter and intra-molecular forces) | | |
| A large amount of energy is required to break intermolecular forces in a covalent substance which has a high melting and boiling point over 1000 $^{O}$C. | | |

| | | |
|---|---|---|
| **Equations, mole, stoichiometry** | 18 | 30 |
| Distinction between molecules and atoms | (37.50%) | (62.50%) |
| Law of conservation | | |
| Comparing reaction coefficients | | |
| Definition of mole | | |
| Confusion about treating mole as a number or quantity of matter | | |
| Use of ratio and proportional reasoning for molar problems | | |
| Increasing amount of reactant and effect on concentration | | |
| Increasing concentration and effect on mole ratio | | |
| Increase in amount of reactant and effect on rate of reaction | | |
| Unclear distinction between molecules and atoms | | |
| Non observance of law of conservation | | |
| Comparing reaction coefficients | | |
| Several definitions of mole (a number, an individual unit of mass, portion of a mass) confusing for trainees | | |
| Confusion about treating mole as a number or quantity of matter | | |
| Use of ratio and proportional reasoning for molar problems | | |
| Increasing amount of reactant and effect on concentration | | |
| Increasing concentration and effect on mole ratio | | |
| Increase in amount of reactant and effect on rate of reaction | | |
| The idea that the formula ratio of a compound could change if subjected to heat or pressure | | |
| The subscript used as number of moles | | |
| Ratio of coefficients used as ratio of masses | | |
| **pH** | 16 | 32 |
| Equating pH to concentration | (33.33%) | (66.67%) |
| Interpretation of the pH scale in practical situations | | |
| Equating pH to dissociation constants | | |
| Misunderstanding about relationship between concentration of ions, dissociation constants and pH | | |
| Interpretation of the term „buffer" | | |

| | | |
|---|---|---|
| Interpretation and determination of the hydrogen ion concentration and pH of a mixture of weak acids and weak bases | | |
| **Particulate nature of matter** | 21 | 27 |
| Definition of atom, element, compound | (43.74%) | (56.26%) |
| Definition of atom, element, compound were used interchangeably | | |
| Differences between elements, compounds and mixtures | | |
| Inability to discriminate between particulate representations of compounds and elements | | |
| An element can split up into two atoms, for example hydrogen ($H_2$) | | |
| An element is part of an atom an element is made up of one *substance* | | |
| If a substance did not feel hard, with a fixed form, such as powdered sulphur it was not classified as solids. | | |
| The trainees failed to use the „particle idea‟ in their analysis of the concept of solids | | |
| Matter is made up of discrete particles which are in constant motion yet have bonds between them | | |
| When the temperature of solids increase, the bonds break and particles „melt‟ | | |
| The attractive force makes particles „clump together‟ if the force is strong | | |
| The states of matter were not easily comprehended (for example how $H_2O$ (l) could be $H^+$ (aq) and $OH^-$ (aq) and not (l). | | |
| Physical change has taken place because the atoms are the same | | |
| Physical change implies there is no change of state | | |
| Chemical change occurs when the arrow is straight forward and not reversible | | |
| Chemical change is when different states result | | |
| **Hybridisation** | 13 | 35 |
| Concept of „mixing‟ up of atoms confused with mixing up of atoms | (27.08%) | (72.92%) |
| Inability to comprehend the idea that „empty‟ orbitals mixing up. "Electrons must be present. How can the orbitals mix up? Where will electrons come from to fill in the hybrid orbital?" | | |
| **Solubility** | 10 | 38 |
| Poor concept of solutions and solubility rules | (20.83%) | (79.17%) |
| Poor concept of solutions and solubility rules | | |
| Over generalisation of solubility rules | | |

Managing super- and subscripts in solubility calculation

The idea that substances „disappear" in solution during dissolution

Inability to comprehend the idea of „ions"

**Appendix K: Improved ACs (post MCT responses versus pre-MCT responses in percentages)**

| Identified alternative concepts | Trainees with correct responses in pre-test (%) | %t correct post-test responses |
|---|---|---|
| **Acid-base strength and reactions** | 23 (47.916%) | 77 |
| Acids with more than one replaceable hydrogens are stronger than those with only one | | |
| A strong solution contains more of an acid than a weak one | | |
| The quantity of an acid or base determines its strength | | |
| A concentrated acid or base is one which is strong | | |
| A weak acid or base is one which is dilute | | |
| **Periodicity** | 22 (45.83%) | 59 |
| Reaction of metals with water | | |
| Trends across and below | | |
| Explanations of anomalies | | |
| Chemical reactivity, bonding and stability of compounds | | |
| Periodic parameters | | |
| Analysis of ions | | |
| **Chemical bonds** | 38 (79.17%) | 82 |
| Bonds have energy between them from the atoms concerned | | |
| Breaking chemical bonds releases the energy | | |
| Ionic bonds are stronger than covalent bonds and difficult to break | | |
| Electron configuration determines number of chemical bonds | | |
| **Equations, mole, stoichiometry** | 22 (45.83%) | 64 |
| Comparing reaction coefficients | | |
| Definition of mole | | |
| Confusion about treating mole as a number or quantity of matter | | |
| Use of ratio and proportional reasoning for molar problems | | |

| | | |
|---|---|---|
| Increasing amount of reactant and effect on concentration | | |
| Increasing concentration and effect on mole ratio | | |
| **pH** | 25 (52.08%) | 78 |
| Equating pH to concentration | | |
| **Particulate nature of matter** | 32 (66.67%) | 68 |
| Definition of atom, element, compound | | |
| **Hybridisation** | 21 (43.74%) | 57 |
| Concept of „mixing" up of atoms confused with mixing up of atoms | | |
| **Solubility** | 19 (39.58%) | 59 |
| Poor concept of solutions and solubility rules | | |

**Appendix L: Percentage of pre-TTT correct responses versus post-TTT responses (N=48)**

| Identified alternative concepts | Trainees with correct responses | % correct Post–test responses |
|---|---|---|
| **Acid-base strength and reactions** | 16 (33.33%) | 51 |
| Acids with more than one replaceable hydrogens are stronger than those with only one | | |
| Strong acids corrode faster than weak acids | | |
| Strong solutions contain more acid than a weak one | | |
| The quantity of an acid or base determines its strength | | |
| A concentrated acid or base is one which is strong | | |
| A weak acid or base is one which is dilute | | |
| **Periodicity** | 12 (25%) | 49 |
| Nature of elements | | |
| Reaction of metals with water | | |
| Trends across and below | | |
| Explanations on anomalies | | |
| Chemical reactivity, bonding and stability of compounds | | |
| Periodic parameters | | |
| Analysis of ions | | |
| **Chemical bonds** | 20 (41.67%) | 70 |
| Bonds have energy between them from the atoms concerned | | |
| Breaking chemical bonds releases the energy | | |
| Ionic bonds are stronger than covalent bonds and difficult to break | | |
| Electron configuration determines number of chemical bonds | | |
| **Equations, mole, stoichiometry** | 18 (37.50%) | 66 |
| Distinction between molecules and atoms | | |
| Law of conservation | | |
| Comparing reaction coefficients | | |
| Definition of mole | | |
| Confusion about treating mole as a number or quantity of | | |

| | | |
|---|---|---|
| matter | | |
| Use of ratio and proportional reasoning for molar problems | | |
| Increasing amount of reactant and effect on concentration | | |
| Increasing concentration and effect on mole ratio | | |
| Increase in amount of reactant and effect on rate of reaction | | |
| **pH** | 16 (33.33%) | 56 |
| Equating pH to concentration | | |
| **Particulate nature of matter** | 21 (43.74%) | 81 |
| Definition of atom, element, compound | | |
| **Hybridisation** | 13 (27.08%) | 33 |
| Concept of „mixing" up of atoms confused with mixing up of electrons | | |
| **Solubility** | 10 (20.83%) | 34 |
| Poor concept of solutions and solubility rules | | |

**Appendix M: Conceptual (scientific) answers for tested concepts**

| Topic | Scientific conception |
|---|---|
| Particulate nature of matter | A chemical change involves the breaking/forming of strong chemical bonds or it is a change where a new substance is forms. A great deal of energy is given out in such a change |
| | A liquid in which salt or sugar is dissolved may have its characteristic taste because its molecules are dissolved in the solution. |
| | 130g of water + 45g of NaOH = 175g NaOH solution. The NaOH pellets dissolve but is still a part of the solution *(same concept used under solubility)* |
| | An element is a pure substance which contains identical atoms or molecules with one type of ionic |
| Chemical bonding | Bonding is a process of bond formation |
| | Covalent bonding is the sharing of electrons between atoms of non-metallic elements which result in a noble gas configuration electronic structure in the valence shell of the atoms involved |
| | Covalent bonding is the electrostatic force of attraction between the positively charged nuclei involved and the shared electrons |
| | Ionic bonding is the electrostatic force of attraction between the oppositely charged ions formed as a result of the process of electron transfer |
| Periodicity | An element is one type of atom or molecule with only one type of atomic core. In a compound, there is one type of molecule; each molecule will have more than one type of atomic core |
| Hybridisation | Orbitals without electrons mix up since the „mixing up" is between „energy levels" which are quite close. |
| | Quantum models were used to explain why orbitals hybridise |
| Solubility | 130g of water + 45g of NaOH = 175g NaOH solution. The NaOH pellets dissolve but are still a part of the solution. Ions in solution come from water and NaOH. |
| Equations and stoichiometry | The first thing to do when solving stoichiometric problems is to write out the stoichiometric equation |
| Acid-base | The Lewis acid-base concept was explained using a combination of the acidity-electrophilic and basicity-nucleophilic concepts. |
| | Clearer distinctions were made between the Lewis concepts and the Bronsted-Lowry and Arrhenius concepts better. |
| | For example, $P(OH)_3$, (that is $H_3PO_3$) is an acid and not a base, regardless the many visible (OH). It has no electron pairs. $PH_3$, on the other hand is a Lewis base because it has available electron pairs. |

| | |
|---|---|
| | In a strong acid virtually all of the molecules dissociate to give hydrated hydrogen ions and anions in solution. In a weak acid only a proportion of the molecules dissociate so there are solvated molecules present as well solvated ions.<br><br>A concentrated acid has a relatively large amount of solute dissolved in the solvent.<br><br>If the concentration of a weak acid is low it dissociates very well because it will have many „hydrated $H^{+}$" ions |
| pH | pH is not synonymous with dissociation constant and hydrogen ion concentration<br><br>pH can be less than zero and greater than 14. As pH reduces, hydrogen ion concentration increases |

**Appendix N: Some interview results on MCE as an interceptive tool for concept formation**

The trainees said that they found the MCE to be a good tool to use to arrest alternative conceptions. They attributed this to the step-wise order in which activities were structured (scaffolded) to enable them gain relevant meaning in the actions that they had to take in their learning processes. They added that the MCE activities were less distractive, in that, they did not have to learn about the operation of equipment as they did in the traditional laboratory activities. In this way, they were able to concentrate better on the tasks that they had to do.

Some of their responses to interview items were:

**Teacher**: What impressions do you have about the MCE approach?

**Trainee 1:** It is ok. ….. it is different from what we have been doing with the glass all this while … mmm… we finish our work on time and we even understand better.

**Teacher**: Did the MCE lessons affect your understanding of concepts

**Trainee 2**: Tremendously, Madam. See, we were learning things by heart. At least, now, I truly understand many concepts on stoichiometry, pH, and hybridisation well. I never truly understood them so I saw them as difficult topics.

**Teacher:** Was time allotted for your activities adequate?

**Trainee 3:** Yes. We even finished our work, often earlier than the time you gave us.

**Teacher:** Do you have any suggestions to make to improve this MCE approach?

**Trainee**: (Laughs) Yes. You can tell other lecturers to use this equipment also. May be it will help us to understand their lessons better also.

Some of the **alternative concepts** which trainees attested to having prior to the MCE approach were:

1. Salts which result from acid-base neutralisation reactions hydrolyse to give neutral solutions in water (MF 18)
2. Acid strength is determined by concentration and loss of electrons (MF 13, MF 20)
3. Solutions having the same molarity, volume, and number of H in the their formula have the same pH (MF 23)

4. Poor distinction between the descriptive terms „weak and dilute", as well as „strong and concentrated" for acids (A weak acid is a solution which has a low molarity such as 0.0001M while strong acid solutions will have molarity of about 0.5M or more. A dilute acid is also weak or has less acid) (MF 13, MF 20)
5. Misconceptions about pH and acid strength (A high pH implies a strong acid) (MF 20)
6. Notions about pOH and base strength (A low pH means a strong base) (MF20)
7. Confusion over mole ratio and its application (MF 21)
8. Misinterpretation and overuse of the term „substance" (MF 24)
9. Mix up about stoichiometric coefficients and subscripts (MF 31, MF 18)
10. The misunderstanding that ionic bonding is possible in hybridisation. (MF 22)
11. Salts formed from neutralisation reactions are all neutral species (MF 18)
12. Germanium can become a liquid at room temperature because the bonds „melt", become weak or break down (MF 19, MF 24)

Then **some of the scientific concepts** which they said emerged after their MCE activities were:

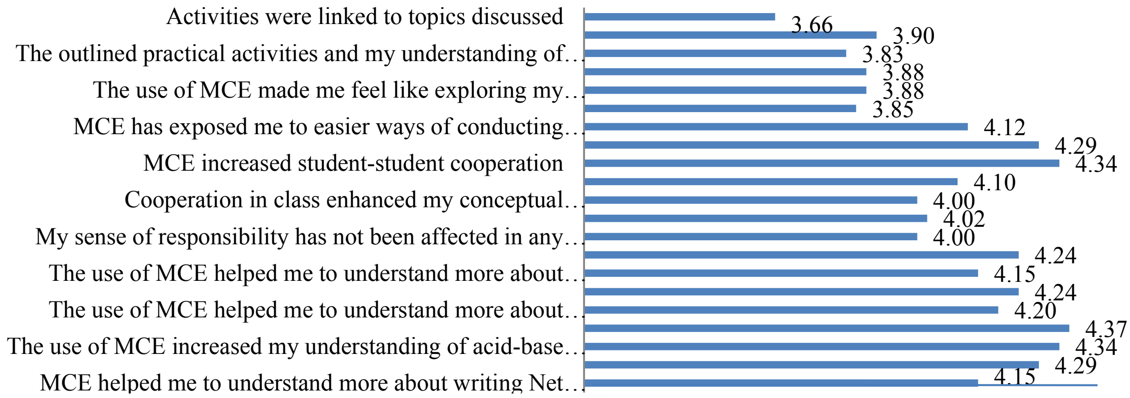
1. Acid strength is determined by the degree of dissociation of an acid species to release [$H^+$] ions in solution (MF 19)
2. Ionic bonds are not necessarily stronger than covalent bonds (MF 24)
3. A negative ion can be bonded to any neighbouring positive ion, if it is close enough (MF 19, MF 24)
4. Different theories such as the Lewis theory can be used to explain acid-base reactions (MF 8)
5. Bases are not the opposite of acids. They have their own unique characteristics (MF 30)
6. Salts formed from neutralisation processes could result in basic, neutral or acidic in solution, depending on the acid and base strengths of the reactants and their conjugate products (MF 18)
7. The stoichiometric ratios could be used in determining the amount of substance in the reacting species if the amount of substance of one of the species is known (MF 21, MF 30, MF 24)
8. The subscripts in a stoichiometric equation are not used to determine the „amount of substance" of a species, but rather the coefficients (MF 21, MF 24).
9. Change in volume or concentration of reactants do not alter their reaction coefficients The volume of the 0.10 M sodium hydroxide solution required to titrate acid B was twice that required for acid A. Since the volume and concentration of both acids is the same, this indicates

that every molecule of acid A is a source of one hydrogen ion or proton (monoprotic) while every molecule of acid B is a source of two hydrogen ions or protons (diprotic). Examples of formulae of two such possible acids are: HC*l* and $H_2SO_4$ (MF 21)

10. Hybridisation involves the mixing up of native orbitals of about the same energies. Bond formation is through covalency (MF 22)
11. The reactivity of metals with other species is not dependent on the „their desire" to form the duet or octet (MF 8).
12. The value for Ka reduces in a dilution process while the value for Kb increases (MF 20 )

## Appendix O: Some statistical data on questionnaire responses from the MCE study

The statistical mean values for the stated items on part A of the students‟ questionnaire has been illustrated using a 5-point Likert scale. The outcomes were all relatively high when responses were analysed statistically using SPSS Version 16.0. Figure 6 (below) is a graphical representation of students‟ impressions about how the MCE affected their conceptual understanding.




**Graphical representation of MCE the effect of MCE on trainees' concept understanding**

## Appendix P: Descriptive statistics for the MCT and TTT tests

**Descriptive statistics for the Two-Tiered Test**

| | Minimum | Maximum | Mean | Std. Deviation | t | Sig (2-tailed) |
|---|---|---|---|---|---|---|
| Students' pre-test score in the Two-tiered test | 20.00 | 56.00 | 34.2083 | 7.00443 | 33.84 | 0.000 |
| Students' post-test score in the Two-tiered test | 26.00 | 76.00 | 54.7917 | 11.02021 | 34.48 | 0.000 |
| Students' changed scores in the Two-tiered test | -6.00 | 46.00 | 20.5833 | 10.30768 | 13.86 | 0.000 |

**Comparative analysis of trainees' performance in the MCT and TTT with the use of the MCE**

| | Min. scores | Max. score | Mean | Skew | F | Sig |
|---|---|---|---|---|---|---|
| MCT Changed scores | -10 | 26 | 6.17 | .070 | 0.566 | 0.907 |
| TTT Changed scores | -6 | 46 | 20.50 | -.097 | 3.652 | 0.001 |

**One-sample test analysis of trainees' performance in the Pre- and Post-MCT**

| | Mean Difference | Standard deviation | t | Variance | Sig (2-tailed) | Standard error |
|---|---|---|---|---|---|---|
| Score in Pre-test | 59.77 | 7.75 | 52.84 | 69.14 | .000 | 1.13 |
| Score in post-test | 65.28 | 10.54 | 42.47 | 111.03 | .000 | 1.54 |

**Paired sample correlation of changed post- intervention test scores for MCT and TTT**

| | Correlation | Significance | t | Sig 2-tailed |
|---|---|---|---|---|
| MCT changed scores & TTT changed scores | 0.327 | 0.023 | -9.033 | 0.000 |

**Appendix Q: Statistical analysis on the usefulness of the MCE**

**Statistical analysis of students' impressions on the usefulness of the MCE approach in practical sessions**

| | | Mean Square | F | Sig. |
|---|---|---|---|---|
| Doing pre lab discussions | Between Groups | 5.077 | 9.622 | .000 |
| | Within Groups | .528 | | |
| Predicting what will happen in a given experiment | Between Groups | 4.337 | 9.948 | .000 |
| | Within Groups | .436 | | |
| Doing experiment and seeing the results myself | Between Groups | 4.213 | 4.957 | .002 |
| | Within Groups | .850 | | |
| Doing the recall questions in the prelab | Between Groups | 4.404 | 6.761 | .000 |
| | Within Groups | .651 | | |
| Doing post lab discussions | Between Groups | 4.325 | 9.292 | .000 |
| | Within Groups | .465 | | |

**Usefulness of the MCE (Percentages)**

| **Usefulness of MCE for basic chemistry activities** | **1** | **2** | **3** | **4** | **5** | **Mean** | **2-tail Sig** | **t-value** |
|---|---|---|---|---|---|---|---|---|
| Pre-lab discussions | 2 | 2 | 21 | 32 | 43 | 4.11 | .000 | 29.20 |
| Post-lab discussions | 6.4 | 0 | 8.7 | 27.7 | 57.4 | 3.91 | .000 | 30.48 |
| Analysis and explanation of experimental results | 2 | 9 | 9 | 38 | 42 | 4.34 | .000 | 27.84 |
| Recall in Pre-lab | 2 | 6.4 | 17 | 40.4 | 43 | 4.11 | .000 | 27.43 |
| Personal experience with MCE to get results | 4 | 4 | 6.7 | 23 | 68 | 3.98 | .000 | 27.59 |
| Prediction of outcome before an activity | 2 | 4 | 17 | 53 | 24 | 4.36 | .000 | 33.43 |
| Preparation of work solutions | 10 | 10 | 28 | 19 | 20 | 3.75 | .000 | 26.42 |
| Relating practice to theory/ Translating theory into practice | 6 | 4 | 27 | 30 | 33 | 4.46 | .000 | 35.53 |

## Appendix R: Ease of use of the MCE to demonstrate conceptual understanding

**Trainees' responses to the ease of use of MCE in demonstrating understanding**

| Ease of use of MCE | Easy (%) | Not easy (%) |
|---|---|---|
| The use of MCE made me feel like exploring my understanding of other topics, still using the MCE | 78 | 22 |
| The use of MCE has given me confidence in planning other basic activities on my own | 78 | 22 |
| It has exposed me to easier ways of conducting chemistry experiments | 82 | 18 |