MICRO-SCALE EXPERIMENTATION AS A CATALYST FOR IMPROVING THE CHEMISTRY CURRICULUM IN TANZANIA

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Preface

Working on a PhD dissertation can be a lonely and isolating experience, yet it is obviously not possible without the support of many people, both at personal and organizational levels. As the Kiswahili proverb says "*Mkono mmoja hauchinji ng'ombe* - meaning *one hand cannot slaughter a cow*". The completion of this dissertation was made possible thorough the support and cooperation of many individuals and organizations. I would like to thank all who contributed in one way or another to make the study a success. The list is too extensive to acknowledge all individually, nevertheless, a few deserve special mention.

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Fidelis M. S. Mafumiko
Enschede, February 2006

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LIST OF ABBREVIATIONS

ACSEE	Advanced Certificate of Secondary Education Education
BEST	Basic Education Statistics
CBN	Chemistry, Biology and Nutrition
CK/SMK	Content (Subject Matter) Knowledge
CSEE	Certificate of Secondary Education Examination
ETP	Education and Training Policy
GDP	Gross Domestic Product
GER	Gross Enrolment Ratio
INSET	In-service Education and Training
$KMnO_4$	Potassium Permanganate
MOEC	Ministry of Education and Culture
MRALG	Ministry of Regional Administration and Local Government
MSCE	Micro-Scale Chemistry Experimentation
MSTHE	Ministry of Science Technology and Higher Education
NECTA	National Examination Council of Tanzania
NCGD	Non-equivalent Control Group Design
NER	Net Enrolment Ratio
PCB	Physics, Chemistry and Biology
PCK	Pedagogical Content Knowledge
PCM	Physics, Chemistry and Mathematics
PSLE	Primary School Leaving Examination
SESS	Science Education in Secondary Schools
STIP	Science Teacher Improvement Project
TEAMS	Teacher Education Assistance in Mathematics and Science
TIE	Tanzania Institute of Education
UDSM	University of Dar es Salaam

CHAPTER 1
Introducing the MSCE study

This chapter introduces the study on Micro-Scale Chemistry Experimentation (MSCE) as a catalyst for improving the chemistry curriculum in Tanzania. Section 1.1 provides an overview of the background of the study. Section 1.2 explains the role of practical work (and its constraints) in Tanzanian secondary education. The features of micro-scale chemistry for improving practical chemistry teaching in secondary education are outlined in section 1.3. Section 1.4 presents the MSCE study's aim and research questions. The research approach adopted in the MSCE study is described in section 1.5. A more detailed elaboration of issues raised in this short introductory chapter follows in the next chapters. Section 1.6 presents an overview of the subsequent chapters.

1.1 ORIGINS OF THE STUDY

With support from the donor community in the mid-1990s, the Tanzanian government commissioned a study to investigate the country's science teaching (Chonjo, Osaki, Possi, & Mrutu, 1996) in an effort to reform its secondary education sector. It became apparent from the situational analysis that there were deep-rooted problems of teaching and learning science in most schools. Problems rooted in science teaching pedagogy, curriculum, examinations, laboratories, equipment, and consumables were among the top aspects in the report. The study revealed that while most teachers did have adequate content knowledge of their respective subjects, they were weak in teaching methodology, particularly on how to conduct and manage student practical lessons. Mathematics and Science teachers' access to regular In-service Education and Training (INSET) programmes to update their knowledge and skills was reported to be very limited. The traditional teacher-centred "chalk and talk" teaching method appeared to still dominate most lessons. In relation to curriculum, the analysis showed that science syllabuses were severely overloaded with content, and the examination requirements compelled teachers to teach in a rush to cover the syllabus. For laboratories, equipment, and consumables, the situation was reported as critical. Resources for carrying out practical work were very limited. Practical work rarely occurred in most schools as standard equipment and chemicals required were too expensive and teachers had limited competence in utilising them. Subsequent studies (e.g. Chonjo, 2001; Mafumiko, 1998; Mshashu, 2000) showed that the situation in schools remained relatively unchanged, especially in relation to practical work, quality, and quantity of teachers. In addition, there was also a shortage of textbooks.

In view of these findings, the need for reform in science teaching and learning in secondary schools was seen as inevitable. Strengthening both pre-service and in-service science teacher education at the diploma and degree levels was considered vital to the reform efforts. Similarly, improving teaching and learning materials (access and availability of textbooks, laboratory, equipment, and chemicals) in the schools was considered equally important in these efforts. Therefore, the Tanzanian Ministry of Education and Culture (MOEC) and other education stakeholders initiated improvement efforts such as collaborative donor-funded projects, which aimed to improve science education provisions in secondary schools. Among the established projects were Science Education in Secondary Schools (SESS), Science Teacher Improvement Project (STIP), and Teacher Education Assistance in Mathematics and Science (TEAMS).

SESS and STIP focused on the ordinary levels of science curriculum. The SESS project operated in government schools, while STIP operated in non-government schools. However, activities of both projects used a similar improvement strategy of equipping schools with textbooks and science apparatus, as well as running in-service education programmes for teachers and school heads. Although these projects' activities were very inspiring, a thorough evaluation of their impact was rarely conducted (Coppard, 2004; Osaki, 1999).

The TEAMS project on the other hand, focused on both pre-service and in-service teacher education and worked mainly with undergraduate students at the University of Dar es Salaam (UDSM) and A-level mathematics and science teachers. Aiming to assist with the production of more and better-qualified science and mathematics teachers, the TEAMS project carried out a number of activities (e.g. development of new courses for science teacher education programmes at UDSM, design of a Masters of Education programme, writing of in-service education materials, and running in-service courses). The main achievements from these activities are summarized in Osaki, Ottevanger, Uiso & van den Akker (2002). This study was conducted within the framework of the TEAMS project. The study aimed at contributing to the implementation of practical work in the A-level chemistry curriculum. The role of practical work in Tanzanian secondary education is further elaborated in the next section.

1.2 ROLE OF PRACTICAL WORK

The role of practical work in science education has been well rehearsed in most science education literature (Eijkelhof, 2002; Hodson, 1993; Millar, 1991). Many reasons are given for using practical work in school-based science education. Practical work provides an opportunity for students to go beyond the words and abstract symbols elucidating points of theory or concepts; it helps students to develop and acquire scientific skills by illustrating how scientists work. It also motivates students by stimulating their imagination and curiosity. Furthermore, practical lessons provide students the opportunity to interact with their teachers and each other on a less formal basis than normal lessons. It also provides teachers valuable opportunities for direct teaching. To what extent these roles are achieved vary from country to country depending on the availability and quality of both human and material resources, and the nature of curriculum and assessment methods used to determine student achievement.

Practical work forms an essential component of science education provision in secondary schools in Tanzania. Ideally (in the official curriculum) every class at both the O-level and A-level are supposed to do practical work. In terms of assessment, it constitutes 40 percent of the final examination grade for both Form 4 and 6. Despite intentions to organize practical work in all Forms, however, current practices show that the frequency has been less than what is required officially. Instead, practical lessons are conducted mainly as a preparation to final examination, which limits both teachers and students to focus only on a few topics appearing regularly in the examination papers.

These studies reveal (Chonjo et al., 1996, 2001; Mafumiko, 1998; Osaki, 1999) that the sciences (Physics, Chemistry, and Biology) are taught mainly, if not exclusively, through lectures in the classroom in Tanzanian secondary education. The frequency of practical work in many schools is far less than what is stipulated by the government. Time for laboratory work is not set aside as much as it should be and some of the laboratory hours are converted to theory classes. There are many reasons for this: lack of resources and facilities, lack of time, shortage of teachers, lack of expertise and confidence among teachers, lack of technical assistance, and the nature of curriculum and examinations. Previous studies in Tanzanian science education document these reasons in detail (Chonjo et al., 1996, Chonjo & Welford, 2001; Osaki, 1999). In a study exploring current practices and potential alternatives in chemistry laboratory teaching in Tanzanian schools, Mafumiko (1998) identified similar obstacles hindering implementation of chemistry practical work in schools. Although practical work is seen as an integral part of teaching and learning science in Tanzania, these problems suggest that applying student-cantered teaching approaches through practical work is far from a reality in many classrooms. On the other hand, it has been argued that practical work need not be an expensive activity. Introduction of low-cost, small-scale methods accompanied with appropriate packages to support teachers can help resolve some of the problems of practical work in chemistry. Micro-scale chemistry is one example of a promising low-cost teaching approach, which has been adopted in some countries to address problems associated with teaching chemistry and implementing practical work.

1.3 MICRO-SCALE CHEMISTRY EXPERIMENTATION AS A PROMISING INTERVENTION

Micro-scale chemistry is a way of conducting chemistry experiments on a reduced scale by using small quantities of chemicals and often simple equipment (Rayner-Canhan, 1994; Skinner, 1997). Experimenting on the micro-scale level provides students the opportunity to do more hands-on activities in a short period of time; this in turn, allows teachers more time for discussion and reflection on the chemistry behind the experiments. Practical work carried out on a micro-scale requires only limited equipment and the amount of chemicals needed is reduced to an absolute minimum. The use of micro-scale chemistry is not restricted to the laboratory. Instead, it can be used in an ordinary classroom with few hassles. This provides teachers more flexibility in carrying out practical work and makes the integration of practical work and theory more feasible than is presently the case where practical work must be conducted in well equipped laboratory and theory lessons are taught separately.

Recent studies show that the micro-scale approach in chemistry is a promising alternative to conventional laboratory experiments in promoting student practical work in schools (Bradley, 2000; Singh, Szafran & Pike, 2000; Thulstrup, 1999; Towse, 1998). A review study on the micro-scale approach by Towse (1998), which cites several other studies from different countries (e.g. Bradley & Vermaak, 1996; Caro, 1995; Corley 1995; Schultze, 1996), shows that high school students had a very positive attitude towards micro-scale chemistry. Findings reported from these studies include, among others, enhancement of student laboratory skills, more focus on understanding of the concepts rather than on the manipulation of equipment, and more time allowed for questions, discussions, and feedback. Moreover, experiments on a micro-scale have other several advantages: they make it easier to understand underlying ideas, are safer to carry out, create less waste, and are fun and easy for the students. South Africa, Cameroon, Uganda, and Kenya have been cited as examples within Africa where micro-scale chemistry has been very positive to both teachers and students (Sia, 2002).

The positive results of microscale chemistry seem encouraging enough for Tanzania, where both human and material resources are inadequate in most schools. Initial exploration on the use of microscale chemistry methods in Tanzanian secondary schools was carried out by Mafumiko (1998). Findings from this study showed that teachers had positive feelings about the possibility of using micrsocale experiments in practical chemistry teaching. In their responses, teachers expressed that microscale experiments could be easy to implement in the classroom and had the potential to reduce chemical and equipment costs. However, since this study was limited to teachers and was not tried out with students in a real classroom setting, a follow-up study focusing on the design, development, and implementation of micro-scale chemistry practical activities in a real classroom setting was considered to test the practicality and effectiveness of the approach in a Tanzanian school environment. This exploration, therefore, served as a base line study for the Micro-Scale Chemistry Experimentation (MSCE) study.

1.4 AIM OF THE STUDY

The aim of the MSCE study was to investigate the possible use of a small scale-low cost approach to practical work that could contribute to improving teaching and learning chemistry in Tanzanian secondary schools. It thereby focuses on the introduction of micro-scale experiments as a means to perform practical activities in chemistry classes, hence reducing the need for highly equipped laboratories, but also providing opportunities for students to engage in a process of active learning. With this focus, the study intended to design and evaluate a promising intervention of micro-scale experiments and supporting curriculum materials that can contribute to the implementation of practical work in the A-level chemistry curriculum. The central research question that guided this study was formulated as follows:

What are the characteristics of micro-scale chemistry materials that contribute to the initial implementation of practical work in chemistry education in Tanzanian secondary schools?

Micro-scale chemistry is a relatively new approach in the context of Tanzanian secondary science education. In exploring the use of this approach, the design and evaluation of curriculum materials focused on validity and usability of micro-scale chemistry as an instructional technique to the current curriculum, the support needed for teachers to use the approach, and the learning outcomes of students associated with this approach. Considering these to be important aspects of the research activities, the MSCE study intended to do the following: develop exemplary curriculum materials to support implementation of the MSCE approach in Tanzanian A-level classes; and examine its impact on teachers and students. Regarding these objectives, the following sub-questions were formulated to guide the research activities.

1. *How can exemplary curriculum materials be structured to adequately support teachers with the implementation of the MSCE approach in class?*
2. *What is the impact of the MSCE approach on teaching and learning practices?*

1.5 RESEARCH APPROACH

Development research approach

The MSCE study adopted a development research approach in designing and developing a micro-scale chemistry experimentation method and in supporting curriculum materials for teaching A-level secondary school chemistry in Tanzania. Development research was chosen because of its promise in generating information that provides useful solutions for a variety of design and development problems in often unclear contexts (van den Akker, 1999). Development research provides flexibility in developing an intervention stage-by-stage within the problem context. Hence it provides good opportunity for understanding local implementation conditions and the difficulties teachers experience in the implementation process. The development research approach is particularly relevant and appropriate for developing countries because of its potential impact on the professional development of participants and its capacity to build on that development. (van den Akker, 2002). Recent studies following this line of investigation in contexts similar to the Tanzanian secondary school system (Kitta 2004; McKenney 2001; Ottevanger 2001; Stronkhorst 2001; Thijs, 1999; Tilya, 2003), show great promise in the developmental research approach. This approach is seen as a means to influence educational practice by experimenting with promising interventions and seeing whether they work in real classroom settings. The overall design of this study is described in the next paragraph.

Overall design of the MSCE study

The research design of the MSCE study consists of three main stages. The first stage, the *front-end analysis*, involves a literature review and a context analysis of secondary science (chemistry) education provision in Tanzania. The context analysis gives particular attention to the current status of practical chemistry offered to secondary school students in Tanzania. The literature review (described in Chapter 3) focuses on the role, current practices, and ways of improving practical work in secondary science education as surveyed from many educational systems including both developed and developing countries. Consultations and networking with people working in fields similar to micro-scale chemistry and science education added value to the front-end analysis in the MSCE study. This stage led to the initial design specifications for the micro-scale chemistry exemplary curriculum materials.

The second stage of the study consists of the design and formative evaluation of exemplary curriculum materials (teacher support materials with student worksheets) for Form 5 chemistry students. The exemplary curriculum materials were designed and developed on the topic *Solubility and Precipitation*, selected from the A-level chemistry syllabus for secondary schools in Tanzania. This topic was chosen because of it suitability in exemplifying the use of the micro-scale chemistry approach in practical work. Moreover, many salt reactions take place in aqueous media and are easily performed on a micro-scale. In addition, the solubility and precipitation phenomena provide a good foundation for qualitative analysis in practical chemistry. The development of the curriculum materials uses a cyclic approach of design and formative evaluation so that successive versions of the materials evolve into a final product with empirical evidence of its *practicality*.

The third stage of the study is the summative evaluation of the MSCE intervention. This stage involved field testing of the final version of the exemplary curriculum materials to evaluate the effectiveness of the micro-scale chemistry approach for teaching and learning chemistry in Tanzanian A-level classes. A quasi-experimental, non-equivalent control group design (Creswell, 2002; Martens, 1998) is used to compare the impact of micro-scale chemistry exemplary curriculum materials on student learning. This stage is described in detail in chapter 5.

1.6 OVERVIEW

This thesis consists of six chapters. This first chapter outlines the aim and research approach of the study. *Chapter 2* describes the context, the United Republic of Tanzania, in which the micro-scale chemistry experimentation study has been carried out. The chapter provides background information on the country's geography, economy, and the education system. Following the country's profile, the chapter covers science education programs and their challenges at both the secondary and teacher education levels. *Chapter 3* reviews the literature on practical work in science education by focusing on its aims, current practices, and promising examples of approaches to practical chemistry worldwide with particular attention to sub-Saharan Africa. *Chapter 4* reports on the design and formative evaluation of prototypes of exemplary curriculum materials for the MSCE approach, with aim of exploring its validity and practicality in a Tanzanias classroom setting. The appraisals and classroom trial of the materials are also discussed in this chapter. *Chapter 5* presents the design and results of the summative evaluation of the final version of micro-scale chemistry exemplary curriculum materials. Finally, *chapter 6* presents the main outcomes and conclusions of the study. The chapter ends with recommendations for further study.

CHAPTER 2
Context of the study

This chapter presents the context (Tanzania) in which the MSCE study was conducted. The major aim of this context analysis was to gain a better understanding of the current situation in which the secondary science curriculum is implemented, particularly the A-level chemistry curriculum. Secondly, the analysis intends to generate some ideas that would help in the design and evaluation of micro-scale chemistry experiments for Tanzanian schools. Section 2.1 presents general information about the country. Section 2.2 outlines the Tanzanian education system including the structure of formal education and training, and the school curricula emphasis. Section 2.3 highlights secondary science education programmes and their constraints. A brief description of science teacher education and its constraints is presented in section 2.4. The last section (section 2.5) contains the study summary and conclusions.

2.1 GENERAL INFORMATION ABOUT TANZANIA

The United Republic of Tanzania is comprised of two former sovereign states, namely Tanganyika (currently Tanzania Mainland) and Zanzibar, which merged to form the Union Government in 1964. The Union Government operates under the Union Constitution and has full responsibility for some of its main sectors including Foreign Affairs, Home Affairs, Defense, and some sub-sectors such as Higher Education. Basic education is not part of union matters. Zanzibar has full autonomy over its basic education and has its own administrative structure of the sub-sector.

Tanzania is situated on the east coast of Africa and has a long coastline. Apart from its mainland territory it comprises a number of islands in the Indian Ocean, the largest being Zanzibar and Pemba. The landscape of the mainland is flat and low along the coast but rises up to a plateau constituting the greater part of the country. It contains the highest mountain in Africa, the volcanic Kilimanjaro with an elevation of 5895 meters on its northern border.

Figure 2.1 Map of Tanzania
Source: http://www.newafrica.com/maps

It also has three of Africa's Great Lakes on its borders, Tanganyika in the west, Victoria in the northwest, and Nyasa in the southwest. Tanzania is bordered on the north by Kenya and Uganda, the east by the Indian Ocean, the west by the Democratic Republic of Congo, Burundi, and Rwanda, and the south by Mozambique, Malawi, and Zambia. The climate of Tanzania varies from tropical along the coast to temperate in the highlands.

Tanzania is a large country (the largest among east African countries) with an area of approximately 945,000 sq. km and a population of approximately 34.6 million (World Fact book, 2002). The population density varies considerably from region to region (on average 39 people per sq. km.), with urban areas having a greater concentration of people than rural areas. The country's economy depends heavily on agriculture, which accounts for half of the GDP and employs 80 percent of the work force. The Tanzanian economy is characterized by a small manufacturing sector, which is hardly competitive in the international market. Rural incomes and living conditions have shown little improvement over the past two decades. Skilled human resources are still one of the main bottlenecks for the implementation of many programmes in the country. More investment in human resource development is necessary, especially in the areas of education, agriculture, science, and technology.

2.2 TANZANIA EDUCATION SYSTEM

2.2.1 Management of the education sector

Education and training in Tanzania is managed and co-ordinated by several ministries, though the primary responsibility is given to the Ministry of Education and Culture (MOEC), the Ministry of Science, Technology, and Higher Education (MSTHE), and the Ministry of Regional Administration and Local Government

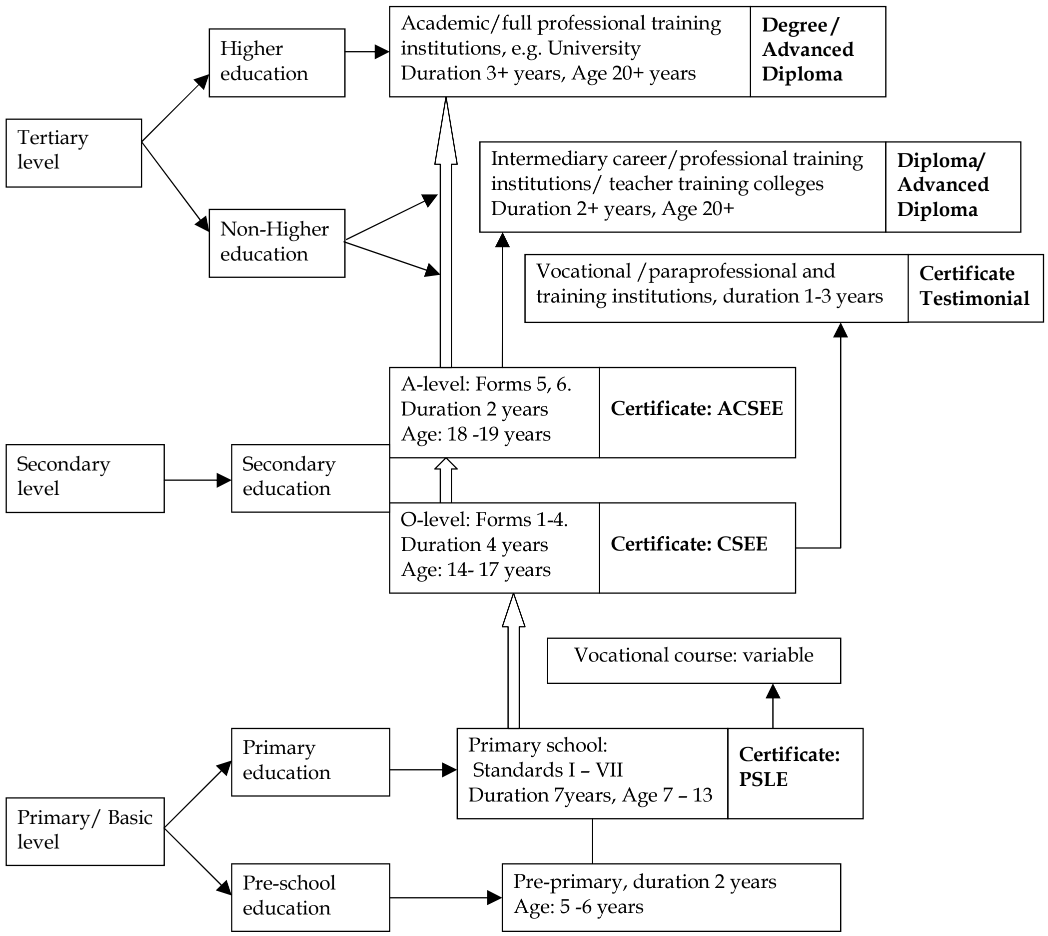
(MRALG). MOEC manages basic education including pre-primary, primary secondary, teacher, and adult education; MSTHE manages tertiary and higher education including the institutes, colleges, and universities; and MRALG administers pre and primary education policies at the grassroots level. Other ministries such as Labour, Youth, and Sports are involved in sector-specific education and training.

2.2.2 Education and training structure

The formal education system in Tanzania is derived from the former British colonial structure. It is predominantly academic and hierarchically divided, ranging from primary to tertiary levels. The nature of this system has for a long time shaped the school curricula and examinations to serve as an important device to select a small minority of students for further education rather than providing feedback on basic life skills and scientific literacy (MOEC, 1995).

The present structure of formal education and training system in Tanzania is 2-7-4-2-3 +, meaning two years of pre-primary education, seven years of primary, four years of ordinary level secondary (O-Level), two years of advanced level secondary education (A-Level), and from three to five years of university education depending on the type of major or faculty; for example, Education, Pharmacy, and Engineering take 4 years while Medicine takes 5. Besides formal schooling there are other channels of post-primary and post-secondary education and training (See Fig.2.2). The promotion of students from one level to another is determined by passing the appropriate selection examinations, which are set externally by the National Examination Council of Tanzania (NECTA) at primary Standard VII, secondary Form 4, and secondary Form 6.

The bigger arrows in Figure 2.2 show the hierarchical nature of formal education in Tanzania, from the primary level up to university based education. Pre-primary education is designed for children, aged 5 and 6 years. However, it has yet to be formalized in the Tanzania school system. Young children are cared for and get initial education at home and in a few available nursery schools, kindergartens, and pre-schools situated in urban areas. For quality delivery, effectiveness, and efficiency of education the Tanzanian government is making efforts to formalize and promote pre-primary education for children aged 5 and 6 years in all government primary schools (Figure 2.2).



Key: ACSEE: Advanced Certificate of Secondary Education Examination; CSEE: Certificate of Secondary Education Examination; PSLE: Primary School Leaving Certificate.

Figure 2.2 Tanzania education and training structure

Primary education

In Tanzania primary education takes seven years (Standards I to VII) and is mostly provided by the state. It is compulsory in enrolment and attendance to all children at age 7. The total enrolment in standard I to VII in 2003 was about 6.6 million, a Net Enrolment Ratio (NER) of 88.5 percent (BEST 2003, see also Table 1). This rate exceeds the government target to enrol 75 percent of the school-age groups by 2002 and it is a challenge to the secondary education sector. At the end of standard seven students sit for the national examination referred to as the Primary School Leaving Examination (PSLE), the outcome of which is used to select those who join government secondary schools to begin Form 1. In addition to PSLE, most private secondary schools, which constitute about 40% of the total secondary schools in the country, have their own entrance examination. However, only a few children have the opportunity to proceed to secondary education; less than 23% of those who complete standard seven are selected to join secondary schools (BEST, 2003).

Table 2.1 *Enrolment in Government (Public) & Non-Government primary schools (Private), 1999-2003*

Type	1999	2000	2001	2002	2003
Public	4182677	4370500	4875764	5960368	6531769
Private	7139	11910	5824	20970	31003
Total	4189816	4382410	4881588	5981338	6562772
%Increase	3.6	4.6	11.4	22.5	9.7
GER (%)	77.1	77.6	84.0	98.6	105.3
NER (%)	57.1	58.8	65.5	80.7	88.5

Note: GER = Gross Enrolment Ratio; NER = Net Enrolment Ratio.
Source: Basic Statistics in Education: 1999 – 2003 National Data.

Secondary education

Secondary education in Tanzania refers to post-primary formal education offered to people who have successfully completed seven years of primary school and have met necessary entry requirements. It is not compulsory and is offered through two subsequent cycles: O-Level and A-Level secondary education. The O-Level begins with Form 1 and ends with Form 4, while the A-Level begins with Form 5 and ends with Form 6. The O-level cycle follows a common national curriculum at the end of which students sit for nationally administered Ordinary Certificate of Secondary Education Examinations (CSEE). A few schools, however, administer the International baccalaureate or the General Certificate of Secondary Education Examinations. Students successfully completing O-level can proceed to A-level, or they can pursue vocational, technical, and professional training, or join the labour market.

The A-level cycle is divided between *science* and *arts* streams. Each stream offers three subject combination options; for example, Chemistry, Biology, and geography (CBG) for the science stream, and History, Geography, and Kiswahili (HGK) for the Arts stream. Again there is a national curriculum and Advanced Certificate of Secondary Education Examinations (ACSEE). The A-level curriculum prepares students for tertiary and higher education, as well as entry into the work force. Thus, students who complete A-level cycle, depending on their performance in ACSEE, can join either university or other tertiary education institutions. Those who do not successfully continue on to higher education join the work force.

Type and ownership of secondary schools

Secondary schools in Tanzania are categorized into government and non-government schools, depending on management and ownership. Government schools refer to those schools owned and funded by the government. This type includes old schools established prior to independence, some of which were previously owned by non-governmental organizations until nationalisation in the late 1960s. Also in this category are community schools, built on a self-help basis by people in local communities with the support of the government—in paying teacher salaries especially. Admission into government schools is decided by national quota, so that children from all over the country have a chance to enrol. Selection is by a cut-off point, however, which may differ from one district to another. Secondary education is not completely free in government schools. There is a cost sharing arrangement where parents pay fees to supplement government funding. At present the government charges USD 40 a year for day scholars and 70 (which is equivalent of Tanzanian shillings 40, 000 to 70,000) for boarding scholars.

Non-government schools are those owned and managed by NGOs, religious institutions, and private individuals and include private and seminary schools. Private schools are owned and operated privately by individuals, companies, NGOs, or groups of people. Seminaries are owned and operated by religious bodies. Private schools admit students who have finished primary school but who couldn't secure a place in a government school and whose parents are able to pay the fees. Another group of students who enrol in private schools are those who have secured admission in government school but who opt not to join because they are not satisfied with the services and performance in final examinations of government schools. Those who join seminaries must have finished primary school and have met the requisite entry requirements. Though not owned by the government, private schools and seminaries are bound to the government in terms of general policy, curriculum, and quality control.

Current enrolment in secondary education

The recent increase in enrolment in primary education (Table 2.1) in Tanzania means an increased demand for access to secondary education. However, the gross and net enrolments ratios for secondary education (a record 7.4 and 6.3 percent, respectively, in 2003) show that very few children have the opportunity to attend secondary education in Tanzania (also see Table2). The transition rate from primary to secondary is currently 21 percent. Nonetheless, the Tanzanian government has created ambitious plans to raise the NER to 50 percent (O-level) and 25 percent (A-level) by the year 2015 (Secondary Education Development Plan, 2002). With this ambition, the Tanzanian government has taken some measures to expand its secondary education sector in order to cope with the increasing enrolment in primary schools. Such measures include deliberate policies to establish day schools and the promotion of the private sector in building new schools (Buretta, 2003). As a consequence of this measure, the number of schools has increased from 190 (86 government and 104 non–government) in 1985 to 1083 (649 government and 434 non-government) registered schools in 2003. These schools accommodated 345,441 (NER of 6.3 per cent). Table 2.2 shows the trend in enrolment of both government and non-government secondary schools.

Table 2.2 *Enrolment in Government (Public) and Non-Government (Private) secondary schools, 1999-2003*

School type	1999	2000	2001	2002	2003
Public	139964	149762	165,800	187343	200720
Private	107615	112134	123 899	135975	144721
Total	247,579	261,896	289,699	323,318	345441
%Increase	9.1	5.8	10.6	11.6	6.8
GER	*	*	*	7.1	7.4
NER	*	*	*	6.0	6.3

Note: GER = Gross Enrolment Ratio; NER = Net Enrolment Ratio.
Source: Basic Statistics in Education: 1999 - 2003 National Data, * = no data available.

2.3 CURRICULUM POLICIES

Until 1995 Tanzania did not have a comprehensive education and training policy. In 1995, though, as part of the efforts to improve its education sector, the government established the Tanzania Education and Training Policy (ETP). The main functions of this policy are to guide, synchronize, and harmonize all structures, plans, and practices; to ensure access, equity, and quality at all levels; and to act as a mechanism for the management, administration, and financing of education and training. In addition, this policy provides guidance and direction for school curriculum policies in the country.

According to ETP the government continues to coordinate and supervise the preparation and delivery of curriculum at primary, secondary, and teachers colleges throughout the Tanzania Institute of Education (TIE). TIE is a semi-autonomous government institute which operates under MOEC and is charged with the responsibility of designing, disseminating, monitoring, and evaluating school curricula for the levels previously mentioned. The institute also writes curriculum materials such as manual guides and textbooks that fit the curricula. In recent years however, the writing of books has been liberalised. TIE continues to publish books only on a small scale. Therefore, schools still depend on imported books which are expensive and unaffordable to most students.

2.3.1 Primary education curriculum

As stated earlier in this chapter, the majority of children leave formal schooling at primary standard seven. The curriculum at this level is therefore intended to balance the requirements of the majority who do not have the opportunity to attend secondary education with the requirements of those few who proceed to secondary education. With this in mind, in 1992, the primary school curriculum was revised and the compulsory subjects were reduced from thirteen to seven. The present curriculum at primary consists of Kiswahili, English, mathematics, science, social studies, life skills, and religious studies. These subjects are further organized into three broad domains examinable at the end of primary school. These are languages (combining Kiswahili and English), general knowledge (combining science, social studies, civics), and mathematics.

2.3.2 Secondary education curriculum

The secondary school curriculum was diversified in the early 1970s into streams—Commerce, Home Economics, Technical, and Agriculture. The options aside from the compulsory subjects vary from stream to stream. However, there is a set of core subjects including mathematics, English, Kiswahili, civics, and biology which are compulsory at O-level, and physics, chemistry, history, and geography which are core but optional after the second year of secondary education. Computer science is also an additional optional subject, introduced in the 1992 curriculum reform. The minimum number of subjects for final examination at O-level is seven. Religious instruction is obligatory to all students.

At A-level, students study subject combinations of their choice, depending on their performance in the National Form 4 Examinations (O-level). Three subject combination options are offered for principal subjects. Civic education (development studies) is a compulsory subject for all A-level students, whereas Basic and Applied Mathematics (BAM) is a subsidiary subject to all students who do not study advanced mathematics.

2.3.3 Examinations and certification

As stated in section 2.2.2, promotion of students from one level to another is determined by the appropriate selection examinations, which are set externally by the National Examination Council of Tanzania (NECTA). In Tanzania, all national examinations for primary, secondary, and teachers' colleges are centrally designed, regulated, conducted, and administered by NECTA. NECTA is a semi-autonomous

government organ established in 1973 following the abolition of the Cambridge Overseas Certificate Examinations. NECTA administers two examinations at the primary school level, one in standard IV, and the other in Standard VII. The Standard IV examinations are conducted at regional level. The standard VII examination marks the end of the primary education cycle and is used for selection of students to secondary education and as a certification of primary education.
As stated earlier, secondary education in Tanzania consists of two complete education cycles: O-level and A-level secondary education. At the end of each cycle there is a national examination designed and administered by NECTA. Successful students are issued two types of certificates: the school-leaving certificates issued by the schools and the academic certificates issued by NECTA. The academic certificates (see Figure 2.2 CSEE and ACSEE) indicate the level of performance in different subjects tested and are issued to students who reach a set minimum mark. The certificates are graded into divisions of one to four, four being the lowest.

2.3.4 Medium of instruction for primary and secondary education

Another important feature in Tanzanian formal education is the bilingual policy, which requires children to learn both Kiswahili and English. English is taught as a compulsory subject in primary education whereas in post primary education it is the medium of instruction. Kiswahili is the medium of instruction at primary education while it is taught as a compulsory subject at secondary education and as an option at tertiary education. There are concerns about the weaknesses brought about by this policy and how they relate to the quality of education. Currently, classroom delivery language practice is an issue in many classes both at secondary school level and higher education. Despite the great effort to improve the use of English in secondary schools, for example, the proficiency in English of both teachers and students is low, and the pressure to switch to Kiswahili medium is mounting.

2.4 SECONDARY SCIENCE EDUCATION IN TANZANIA

Tanzania recognizes the important role science and technology can play in its development. Science, and for that matter science education, influences the quality of people's lives, and develops people's standard of living in all of its elements--economic, social, or environmental. Realizing this, the Government of Tanzania believes school plays an important role in developing the knowledge and skills of Science and Technology among its citizen youth. In the school curriculum, it gives more emphasis to the teaching of mathematics, science, and technical subjects including computer studies in order to promote technological and scientific development in the country (MOEC, 1995). Given this emphasis, the Tanzanian Government, in 1995, implemented a policy stipulating that “Science and Technology shall be essential components of education and training in the whole education system”.

2.4.1 Teaching and learning science

Formal teaching and learning of science begins at primary school and advances with the level. In primary schools students are taught general science. The subject is not taught in great depth, but is limited to the basic concepts of the three disciplines of biology, chemistry, and physics. The learning of these concepts is guided by a common seven year science syllabus throughout the country. The secondary school science curriculum is based on individual subjects. At O-level biology, chemistry, and physics are taught separately as core subjects. In the first two years (Form 1 and 2) of O-level, all three subjects are compulsory for all students. In Form 3 and 4, chemistry and physics are core subjects but optional for students majoring in arts, commerce, and technical disciplines. Each subject has its own syllabus covering content topics for four years of study. Similarly, at the A-level, students majoring in science study biology, chemistry, and physics as principal subjects. These subjects are offered in various three subject combination options including combinations with agriculture, nutrition, geography, and advanced mathematics. Each subject has its own syllabus.

Curriculum implementation at classroom level is guided by the time set nationally for each subject. The maximum curriculum time set aside for each science subject is 2 hours and 40 minutes (4 periods per week) for O-level and 6 hours and 40 minutes (10 periods per week for A-level) (MOEC, 1982). The teaching of these subjects is guided by the time available and the syllabus for each subject. Schools have time tabled lessons as separate theory lessons and lessons for practical work. Likewise, national examinations for science consist of both theory papers and practical examinations, and they take place at the end of Form 4 (O-level) and Form 6 (A-level).
The number of periods allocated for these subjects is determined the government and the time allotment per week is intended to ensure that the syllabus will be covered within the specified time of each programme. However, classroom realities in the schools show that there are several problems that affect the realisation of school timetables (Chonjo, et al., 1996; Knamiller, Osaki, & Kuonga1, 1995; Mafumiko, 1998; Osaki, 1999). The list is extensive and it is not the intention of this chapter to exhaust them all. An assortment of the major problems will be discussed in the next section.

2.4.2 Challenges of teaching and learning secondary science

The quality of science teaching in Tanzanian secondary education is currently in the social discourse. There are several concerns but the main ones are associated with the nature of the curriculum, the quality and quantity of the teaching staff, and the availability of teaching and learning materials including laboratories, equipment, and consumables. Problems in these areas often overlap and sometimes it is not easy to explain one problem area without touching on the other.

The first problem area concerns the quality and relevance of the present secondary science curriculum. Past studies on the situation of secondary science education in Tanzania have indicated that the curriculum is very academic and elitist in nature. An analysis by Chonjo et al. (1996) depicts secondary school science syllabi as too academic and overloaded with too many different topics, many of which are often too difficult and go beyond what is usual in other countries. This situation makes the curriculum irrelevant to most students who normally end their formal schooling at secondary level. Similarly, teachers claim that syllabi are often too long to be covered within the available timeframe. Thus, they are forced to teach in a rush to meet the examination requirements (Leeuw, 2003), which in turn does not contribute to any meaningful learning. Textbooks are inadequately supplied and often imported, which forces schools to use a limited number of prescribed books.

The second concern relates to the availability of qualified teachers in the schools. Currently there is critical shortage of teachers for science and mathematics, especially for A-level schools situated in rural areas (Buretta, 2003; Mushashu, 2000). This has been aggravated by the fact that some graduate teachers avoid teaching and are employed in higher paying jobs. The recent expansion of the secondary education sector has also increased the number of students per class, which does not match the supply of qualified teachers in the school system. Due to the teacher shortage classes are combined to reduce the teaching load. As a result, teaching takes place in overcrowded classes which make little use of the variety of available teaching approaches, such as practical work, group work.

Another closely related problem is the quality of the teaching force. In general, teaching in the sciences in Tanzania is reported as "chalk and talk" and note-giving, emphasizing recall of factual information (Chonjo et al., 1996; Osaki, 1999). According to these studies in most classrooms observed teachers preferred to use lecture methods rather than interactive methods. Teachers lack competence and experience in using such learner-centred teaching approaches as practical work. Teachers' incompetence in employing active learning methods is also reflected in the limited

use of textbooks for classroom activities. Recent studies (Leeuw, 2003 & Kibga 2004) report that in most classes teachers were observed not using textbooks even when they were available. Teachers still preferred to use the 'chalk and talk' method by writing notes on the chalkboard for students to copy in their notebooks. In some cases teachers asked questions and students answered questions but often in chorus.
Osaki (1999) found that students rely heavily on teachers notes because they believe notes are important for the examination. This dependence makes the teacher the sole source of information. According to Osaki there is no reading culture among many students. Although students may have books, they opt to read teachers' notes, which often provide superficial content and encourage memorization of facts.

The third problem concerns the lack and high cost of laboratories, equipment, and consumables. In Tanzania there is great reliance on imported laboratory equipment and consumables, which are prohibitively expensive. Schools cannot afford most of the equipment. In some schools—especially the community aided schools—there are no laboratories. As a result students do not do enough practical work (Chonjo et al., 1996; Mafumiko, 1998; Mshashu, 2000). Time for laboratory work is not utilized as desired and planned. Some of the laboratory hours are converted to theory classes. Practical work is conducted mainly for final year students (Form 4 & Form 6). On the other hand, the findings from these studies show that in some schools that have laboratory facilities practical work is still not done. There are several reasons for this: practical work means extra work for teachers, equipment and chemicals are reserved until examination time, and teachers lack the competence and confidence to carry out practical work. Another impediment to proper teaching in the laboratory is big class size. In most schools the present laboratories were built to accommodate a class of 35 students for O-level and 24 students for A-level, but current classes range from 50 to 70 students for O-level and 35 to 50 A-level.

For chemistry practical work in particular, which is also the focus of this study, Mafumiko (1998) identified several obstacles that hinder effective implementation of chemistry practical work in schools. Some of which are as follows:

- lack of apparatus and chemicals;
- introduction of an alternative paper to the practical examination at O-level;
- inadequate teacher knowledge and skills;
- lack of regular in-service programmes for teachers;
- inadequate time to prepare and mark student practicals;
- lack of laboratory technicians; and
- lack of laboratory manual guide for A-level chemistry.

Initial teachers' responses also showed that a micro-scale chemistry approach could be a promising small-scale low-cost approach for practical chemistry in Tanzanian secondary education.

2.5 SECONDARY SCIENCE TEACHER EDUCATION AND ITS CONSTRAINTS

2.5.1 Pre-service teacher education programmes

The pre-service science teacher education for secondary schools in Tanzania is organized into two levels: college and university.

At the college level the programme takes two years. It enrols Form 6 graduates who have not met minimum entry qualification for the degree program. The two year teacher education curriculum includes academic and professional components. The academic component focuses on enhancing pre-service teachers' content knowledge in the teaching subject (normally two science subjects). The professional component focuses on the provision of foundation knowledge in the principles of education, child psychology, educational management, and pedagogy. Graduates at college level obtain a Diploma in Education and qualify to teach in O-Level schools.

The main institution that offers pre-service teacher education for science teachers at degree level in Tanzania is the University of Dar es Salaam through two faculties: Education and Science. The programme takes four years. Like the diploma programme, degree programmes for pre-service science teachers consist of both academic and professional courses. Academic courses are offered in the faculty of science while professional courses are offered in the faculty of education. The pre-service science teachers study one or two science subjects depending on the programme a student is following. There is no distinction in courses between those for teacher preparation and those for the general science degree programme. The degree teacher education programmes prepare teachers for A-levels and teacher education colleges.

Constraints

The major constraints of the pre-service teacher education programme at diploma level in Tanzania are associated with:

- *under funding*: because of under funding the colleges are forced to close earlier for vacations than scheduled. Teaching practice for diploma students is also truncated because of financial constraints.

- *poor infrastructure*: the majority of the colleges are in poor condition with deteriorating buildings, furniture, textbooks, poorly equipped libraries, and other learning resources (TEMP, 2001). Hence they do not provide a stimulating environment for science learning.
- *lack of balance between academic and professional courses*: Lengthy time is taken to cover academic topics, whereas the pedagogical and didactical aspects are covered in a very superficial manner (Dasu, 2001; Chonjo et al., 1996).
- *nature of examination*: Final examinations for Diploma students do not include science practical component, hence practical work is not emphasised during training.

A general view of pre-service college teacher education programmes in Tanzania is that they do not adequately prepare mathematics and science teachers. Thus, besides a need for improvement of the pre-service teacher education programmes, there is a need for remedial in-service education programmes.

2.5.2 In-service teacher education programmes

Teacher participation in in-service education programmes is considered a good way to help teachers grow professionally. Professional inputs to teachers are regarded to have substantial impact on students (TEMP, 2001). Acknowledging the potential of in-service education for the professional growth of teachers, the Tanzanian Government in its Education and Training policy states that "in-service teacher training and re-training shall be compulsory in order to ensure teacher quality and professionalism" (MOEC, 1995).

In Tanzania, there are two patterns through which in-service education programmes for secondary science and mathematics teachers are conducted. First, teachers are brought to a workshop/seminar from the schools in their regions to, for example, the UDSM to be trained by lecturers from different departments of the Faculties of Science and Education, officials from the Tanzania Institute of Education (TIE), and the Ministry of Education and Culture (MOEC). Another pattern of in-service programmes involves university lecturers and other facilitators organizing in-service training for teachers in their respective zones or regions.

Constraints

Although a policy on in-service teacher education exists, the current level of support for in-service teacher education in Tanzania, for all subjects, is inadequate mainly due to lack of funds and organizational problems. There have been very few in-service education programmes (Kitta 1997; Chonjo, et al., 1996) due to budget constraints facing MOEC. The running of in-service programmes depends mostly upon foreign agencies and donors. The majority of teachers have no access to in-service courses or seminars. Syllabi have changed. In some subjects new topics have been included but teachers have not brushed up, and as a result, new or unfamiliar topics are left untaught (Mshashu, 2000). Many teachers teach "as they were themselves taught" and lack the necessary competences and confidence to tackle practical work at school, in most cases because they never learned this aspect from their own initial teacher education and in their schooling. This is an area where compulsory in-service education for science teachers is needed.

2.6 CONCLUSIONS AND IMPLICATIONS FOR THE STUDY

The primary intention of this context analysis was to develop a better understanding of the impediments to practical work in secondary school science teaching. Specifically, the context analysis aimed at identifying areas of attention in order to generate some useful ideas for the design and evaluation of a micro-scale chemistry approach that is viable within the Tanzanian classroom conditions.

In the analysis it became evident that both primary and secondary education have improved their enrolment in recent years and that the enrolment is likely to double in the next ten years. On the other hand the analysis revealed unparalleled improvements in terms of teaching force, curriculum, and teaching and learning materials especially for secondary sciences. The teaching and learning of science at the secondary level takes place under a very restricted resource environment. Multiple problems surround secondary education provisions in Tanzania.
There is big shortage of teachers in most schools for science and mathematics. As a result some lessons remain untaught because the few teachers who are there cannot handle all classes. Apart from a shortage of teachers, schools have unqualified and underqualified teachers, most of whom have little or no pedagogical content knowledge and skills, as well as experience. Qualified teachers on the other hand lack confidence due to the inadequate teacher education they received in college.

In terms of the teaching and learning environment, the analysis revealed that most schools lacked the necessary and relevant teaching and learning materials including textbooks and laboratory equipment. Despite the curriculum emphasis on practical work, current practice show that most practical work in Tanzania secondary education is offered only for a few students, usually those who are preparing for the national examination. This indicates a huge gap between intentions and realities. Besides the scarcity of resources, schools are challenged with large classes, which hardly allow effective science teaching.

The quality and relevance of the curriculum is another great challenge for teachers, teacher educators, and researchers. In general, the analysis showed that all science syllabi are overloaded, abstract, overly academic, and not responsive to the current needs and future development of the country.

In view of the challenges of teaching and learning science in Tanzanian secondary schools, small-scale and low cost practical work in chemistry teaching was thought to be one potential strategy for improving the implementation of practical work in schools. Based on this analysis and the findings from an explorative study on current practices and alternatives to chemistry laboratory work (Mafumiko, 1998), introducing micro-scale chemistry experimentation in the existing A-level chemistry curriculum was thought to be a promising way to improve secondary science curriculum in Tanzania.

CHAPTER 3
Practical work in science education

This chapter presents the results of the literature study aimed at gaining insight into the role of practical work in science education across various levels. A short description of practical work and its various forms is presented in section 3.1. Section3.2 presents the aims and rationales for practical work in science education as identified by past research. Section 3.3 looks at the effectiveness of school based-science practical work. Section 3.4 examines the current situation of practical work in developing countries. This section pays special attention to factors that promote or limit success in the implementation of practical work in school-based science education. Section 3.5 explores micro-scale chemistry as it has been reported in the literature and its characteristics as a low-cost small scale teaching approach in chemistry. The last section, 3.6, focuses on central ideas for the design and evaluation of the MSCE exemplary curriculum materials.

3.1 DEFINITION AND FORMS OF PRACTICAL WORK

The term 'practical work'—synonymous with other terms such as 'hands-on' activities, 'experiments', and 'laboratory work'—refers to the performance of experiments or practical exercises with science apparatus in a laboratory setting (Woolnough, 1991). Millar, Le Marechal and Tiberghien (1999, p. 36) offer a broader definition of practical work to include all those *teaching* and *learning* activities in science that involve students at *some point* in handling or observing the objects or materials they are studying. In their definition they place no restrictions on where the activity is carried out. Practical work might be carried out in a laboratory, or outside 'in a field' or in an ordinary classroom. The words at 'some point', according to Millar et al., emphasize that practical work involves conceptual as well as practical activities; observing or manipulating real objects and materials is just one element of a practical task. Another aspect is reflection and discussion. In other words, much learning associated with practical work or laboratory experiences takes place through the process of talking about observations, and what they might mean, both with other learners in the class and with the teacher.

Teaching and *learning activities* according to Millar et al., illustrate both student practical activities and teacher demonstrations but do not include any representation thereof, such as simulations.

Practical work has also been defined as any learning method that requires learners to be *active* rather than *passive*; it need not always comprise activities at the laboratory bench (Hodson, 1993).
The above definitions lead to two perspectives of practical work. One perspective is that it encompasses activities carried out in a special place referred to as the *laboratory*. Another perspective is that practical work consists of different forms of activities and can take place in the laboratory, classroom, or elsewhere.

According to Millar et al., (1998) different forms of practical work can have different functions. A clear understanding of these forms is helpful in any attempt to examine or improve the effectiveness of practical work in teaching and learning of science. The first category of these forms is 'typical laboratory exercises', which is used in most countries at some level (s) of the education system. Typical laboratory exercises refer to those teaching and learning activities students interact with real materials and/or equipment, following detailed instructions from the teacher and/or laboratory manual guide. Other forms of practical work—different from a typical laboratory exercise in at least one respect— are those (Millar et al., 1998) in which:

- teachers not students carry out the tasks themselves (teacher demonstrations);
- students do not obtain information from real objects and materials, but from a video recording or computer simulations, a CD-ROM , or even from a text-based account;
- students do not receive full instructions but are required to make some decisions for the themselves (more open-ended tasks); and
- students are asked to undertake only part of a task; for example, they may be asked to propose a plan for carrying out an investigation, or to interpret some given data.

3.2 AIMS AND RATIONALES FOR PRACTICAL WORK

The rationales employed in the promotion of practical work in the secondary school science curriculum can be traced back to the nineteenth century. It was in this century that practical teaching of science became an established feature of science education (Hofstein, 1991; Hodson, 1993; Lazarowitz & Tamir, 1994; Lunetta, 1998). Research by Hodson (1993) and Lazarowitz and Tamir (1994) provides a thorough review on how the purposes of practical work have changed since the 19th century. In the mid-nineteenth century, practical work in laboratories was largely used for confirming and illustrating information learned previously in a lecture or from a textbook. It did not include any genuine experiments, and the procedures and expected results were printed in textbooks. In this period teacher demonstrations were much more widespread than individual experimentation by students. In the latter years of the century, the rationale for practical work shifted from a concern with the promotion of generalized learning skills transferable to other areas of knowledge to a justification in terms of training in scientific method. This orientation remained relatively unchanged until the time of major science curriculum reforms in the 1960s when the laboratory became the centre of science instruction in the intended form of most science curricula (Hofstein, 1991).

The 1960s wave of science curriculum reforms inspired science education researchers to look more into the role of practical work in secondary science education. In their research reviews, Hodson (1993) and Watson (2000) report several studies that have surveyed teachers' views about the nature, purposes, and assessment of practical work in various contexts. However, despite the changes in the kinds of practical work done over time, some of the aims the researchers uncovered have remained relatively unchanged. Although the details vary, such aims share common elements, which are a mix of *content*, *procedural*, and *affective* aims. Bennett & Kennedy (2001) summarizes these aims into eight categories:

- to develop manipulative skills and techniques;
- to encourage accurate observation and description;
- to discover or illustrate a concept or law or principle;
- to experience a scientific phenomena;
- to motivate by stimulating interest and enjoyment;
- to develop understanding of experimental procedures such as open-mindedness and objectivity ; and
- to get a feel for what being a problem-solving scientist is all about.

Although the aims of practical work have remained relatively unchanged, the discussions on what constitutes valid motives for school-based practical work feature in science education literature. Several authors offer further categorization of the goals of practical work (Griffin, 1998; Hodson, 1993, 1996, 1998; Kirschner & Huisman 1998; Lazarowitz & Tamir, 1994). Griffin (1998), for example, considers the main purposes of practical work as follows: to *deepen understanding of scientific ideas, to experience scientific processes; to acquire scientific research skills*. To these main goals, Griffin adds a set of sub-goals including *self-motivation, stimulation of creativity, recognition of relevance of scientific understanding,* and *independent thought*.

Similarly, Woolnough and Allsop (1991) summarize the goals of practical work as gaining *experiences* and doing *exercises* and *investigations*. These two sets of goals are further related in the following descriptions.

- Having *experiences* which facilitate *understanding of scientific ideas*: Practical work can provide experiences that reinforce theoretical ideas the students encounter; it can help them make sense of their world (Griffin, 1998).
- Conducting *exercises* which lead to *acquisition of scientific research skills*: Practical work can be justified for its role in developing the skills of manipulation, scientific procedures, and problem solving. The principal sub-skills that can be developed through practical work are classification, observation, measurement, estimation, planning, execution, interpretation, and applying ideas to new situations. Practical work provides an opportunity for students to learn how to carry out a scientific enquiry (Kirschner & Huisman, 1998).
- Carrying out *investigations using scientific processes*: In order to help students gain experience and understanding of scientific processes they need time to play and experiment both with their hands and ideas, to ask their own questions and seek answers. To achieve this aim, students need practical experiences to develop competence in learning to investigate and in learning to solve problems. Furthermore, in order to attain these sub-skills, students need the chance to discuss, reason, and compare what they have done with other students (Griffin, 1998; Kirschner & Huisman, 1998).

Hodson (1998), on the other hand, points out that while the educational goals for practical work are common to many countries, the means of achieving them are not. There are some widely differing activities coexisting under the umbrella of 'practical work': at one extreme, short, worksheet-driven lab exercises; at the other, lengthy, open-ended student-driven projects. According to Hodson, this situation makes the goals of practical work unclear. Because of the diverse goals of practical work most research findings on the efficacy of practical work are confusing and generally give inconclusive results.

To avoid this confusing and educationally unproductive situation of practical work in science education Hodson (1998) describes the functions of practical work, (also the main goals of science education) as:

- to help students *learn science*: acquire and develop conceptual and theoretical knowledge;
- to help students *learn about science*: develop an understanding of the nature and methods of science and an awareness of the complex interactions among science, society, and the environment;
- to enable students *to do science*: engage and develop an expertise in scientific inquiry and problem solving;

Eijkelhof (2002) adds *motivation for science (i.e.* stimulate students' imagination; arouse curiosity, amaze, surprise, challenge, and show relevance and importance) as the main fourth function of practical work. Each of these goals has a range of sub-goals, for which different teaching approaches are necessary. Hodson suggests that to ensure effective teaching, teachers need to be clear about the sub-goals they have for particular lessons, and must select learning activities specifically suited to their attainment.

3.3 EFFECTIVENESS OF PRACTICAL WORK

Although practical work has long been acknowledged as an integral part (as depicted by the wide variety of its aims) of teaching and learning science at various levels worldwide, its effectiveness has been the subject of debate in most science education literature (Hodson 1993; Hofstein & Lunetta, 2004; Jenkins, 1999; Lazarowitz & Tamir, 1994; Lunetta, 1998, Watson, 2000). The core of such debate centres on the general question asked about 'what is the role of practical work in achieving educational aims' (Watson, 2000). According to Watson, this question appears ambiguous and misleading in attempts to evaluate the effectiveness of practical work. A more focused question should be: 'what kinds of practical activities can be used to achieve particular aims?' A similar question has been suggested by Blosser (1990): 'for what purposes should the laboratory be used, under what conditions, and with what students?' A vagueness about what the practical work should achieve in science teaching has led to all-inclusive results about the educational value of the laboratory as a teaching medium.

Classroom based studies have revealed a mismatch between goals, behaviour, and learning outcomes, which continues to limit the effectiveness of practical work in science teaching (Hodson, 1993; Lunetta, 1998). According to Hodson and Lunetta students often do not have clear ideas about the aims and purposes of their work in laboratory lessons and that their understanding of the goals of lessons frequently does not match their teachers' goals for the same lessons. For many students laboratory work tends to be interpreted as following instructions to manipulate the equipment or get the right answer but not manipulating ideas (the reasoning behind the answers, either correct or wrong).

In his review, Hodson (1993) expresses dissatisfaction for most of the functions of practical work (motivation, acquisition of science skills, scientific knowledge and methods of science, and acquisition of science attitudes). According to Hodson, in most practical lessons, learning experiences children find interesting, enjoyable, and helpful are not given attention. Instead, teachers are more comfortable with easily handled activities than with more open enquiry. Moreover, Hodson points out that empirical evidence about the efficacy of practical work as way of learning scientific knowledge is difficult to interpret and somewhat inconclusive, and thus makes it uncertain whether practical work is better than other methods for learning science concepts.

Giddings and van den Berg (1992) observe a similar weakness of laboratory based teaching. They argue that the distinctions between the priorities and objectives of specific practical activities are rarely made clear in a teaching and learning situation. As a consequence students are expected to learn concepts as well as processes and manipulative skills in the same experiment, a situation which leads to information overload. Due to this overload much of the practical activities become unproductive in terms of student learning. According to Giddings and van den Berg (1992), mismatches between laboratory goals and student behaviours can be avoided by clearly distinguishing the various types of laboratory activities, matched to intended learning outcomes. They distinguish three types of practical work (or labs): *skill labs*, *concept labs*, and *process labs*. The skill lab is the most common of the three and is used to promote the learning of manipulative skills. Concept labs emphasize teaching concepts and overcoming misconceptions. They often refer to carefully designed sequences of activities to promote interaction between students and the experiments. Process labs emphasize intellectual (process) skills needed to generate and validate knowledge experimentally. Giddings and Van den Berg suggest that for effective use of each of these labs careful planning and preparation of teaching approaches and assessment strategies is needed. One way to enhance student learning of practical work is to prepare them for doing the experiments through pre-laboratory discussion or exercises (Gabel, 1998). According to Gabel providing students with separate pre-laboratory discussion prior to practical work helps them think about the science behind the experiments and enhances their attainment of learning objectives in practical lessons.

Another aspect, which features in the science education debate, is the lack of reflection and discussion in students' practical work. Past research shows that practical lessons rarely incorporate student discussion and reflections that provide opportunities to construct shared understanding of scientific concepts as part of a community of learners in the classroom (Lazarowitz & Tamir, 1994; Lunetta, 1998). Lunetta reports that even when discussion takes place during practical lessons, teachers and students tend to focus on procedures rather processes and techniques.

Closely related to the unclear aims of practical work is the lack of focus in science education research in investigating the effectiveness of practical work in achieving educational goals. Often, the usefulness of practical work in teaching and learning science has been measured against other teaching approaches. Millar et al (1999) argue that the issue is not the usefulness of practical work in general. Instead, we should ask about the effectiveness of *specific* pieces of practical work for achieving *specific* learning outcomes. They argue that researchers who intend to explore the effectiveness of practical work in achieving educational goals need to be clear about the different types of practical work undertaken in classes, and their different characteristics, as well as the views of teachers and students on the those practical experiences.

However, despite these weaknesses some studies show the positive outcomes of practical work regarding some of the goals. Arce and Betancourt (1997) found practical work to be an effective motivational strategy, especially when students do and/or design their own experiments. They argue that students find experiments challenging and rewarding. According to Arce and Betancourt (1997), practical work effectively helps students learn science concepts, as it helps them transform abstract to concrete, thereby helping them internalize concepts. In a comparative study to investigate the effects of a cooperative class teaching method on secondary school students' chemistry achievements in Kenya, Wachanga and Mwangi (2004) found that teaching with experiments facilitated students' chemistry achievement more than regular methods. In a similar study, Freedman (1997) concluded that laboratory instructions had a positive influence on students' attitudes toward science and their achievement of science knowledge.
Despite his criticism of school based-science practical work, Hodson (1996) acknowledges that in well-designed and supervised practical work and supportive environments students will be able to enhance their conceptual understanding, procedural knowledge, and investigative expertise.

3.4 CURRENT PRACTICES OF PRACTICAL WORK IN DEVELOPING COUNTRIES

Teacher and student behaviours, and the types of practical activities are important indicators of common practices, of what really happens in the science laboratory or practical lessons. Taken together these play an important role in controlling student learning in science classes. Empirical evidence on the practices and effects of the many intentions of practical work in science education are scarce. Few recent studies document the general instructional patterns or practices of practical work common to many developing countries (e.g. Bekalo & Welford, 1999, 2000; Bradley, 1999; Chonjo et al., 1996; van den Akker, 1998). These practices include the gap between intentions and classroom realities, resources, examination driven practical work, and the limited assessment procedures of student learning in practical work.

3.4.1 Gap between intentions and classroom reality

One of the tenets frequently advocated in national science curricular documents is that teachers should teach science by means of practical or experimental approaches. There is also a strong belief among science teachers and researchers that practical activities can develop various student abilities in science. On the other hand, several studies indicate that in many classrooms there are major discrepancies between the lofty (highly ambitious) goals expressed in the rhetoric of science education and the kinds of activities in which students engage (e.g., Bekalo & Welford, 1999; Chonjo et al., 1996; Ware, 1992). In some classes there is no laboratory work at all. In others there is hands-on practical work, but students work their way through a list of step-by-step instructions (like technicians), trying to reproduce expected results and wondering how to get the right answer. Few opportunities are given to students to discuss experimental results, to hypothesise and propose tests, to design and then actually perform an experiment. Despite the policy emphasis on promoting practical work to science learning in the curricula of many countries, findings from the research suggest that there is a huge gap between ideal learning and what is implemented in the classroom. Bekalo and Welford (1999), for example, found that of the 80 lessons observed in four sample schools only one practical lesson was conducted—a teacher demonstration. They also found that there was little agreement between curriculum objectives and the reality of textbooks, examination papers, teacher-training colleges, and classrooms. This situation is not unique to Ethiopia, as studies in many African countries have reached similar conclusions.

3.4.2 Resources

The level of resources, both in terms of quality and quantity, is another crucial factor in achieving excellence in teaching and learning science. Successful laboratory teaching requires adequate equipment, consumable materials, storage space, published resources including teaching materials and background reading materials for teachers and students, as well as sufficient time. However, the experiences of many developing countries, especially Sub-Saharan Africa, show that the low level of these resources is the major barrier to teaching science practically (Bekalo & Welford, 1999; Bradley, 1999; Chonjo et al., 1996; Mshashu, 2000; Muwanga-Zake, 1998; Nyagura, 1995). Sia (2002), for example, explains that because of shortages in budget, laboratories, chemicals, and because of problems related to repairs and maintenance, science learning in sub-Saharan Africa has occurred mostly through pictures in books, drawings on the blackboard, and examination questions. Although this shortage of labs, equipment, and consumables appears to be a major barrier to practical work there is evidence that even when the equipment is available teachers do no practical work. One reason for this is that equipment and chemicals are reserved until examination time. Another reason is that teachers lack confidence and experience to do practical work (Muwanga-Zake, 1998). The next section further elaborates on teachers' preparedness to practical work.

3.4.3 Teacher preparedness

Teachers' attitudes, knowledge, skills, and behaviours can also affect whether learning during students' practical work attains its objectives. Although many factors influence the nature of learning in students' practical work, the single most important one is the teacher. Effective use of practical work requires a high level of skill proficiency and subject matter knowledge, and a readiness for risk taking on the part of the teacher. Apart from limited equipment, chemicals, and other material resources, studies show that most teachers do not do practical work because they are not clear on what practical work to do, when and how to do it. A study by Muwanga-Zake (1998) is a case in point. In the study, teachers' deficiencies in practical skills and their lack of understanding of some chemical concepts were found to limit their ability for practical work in chemistry in some South African schools. One major reason for the teachers' limited knowledge and skills in practical work is the inadequacy and/or inappropriateness of their education (during their initial preparation at college). Many authors report that pre-service teacher education programmes are deficient in terms of practical work (Bekalo & Welford, 1999; Bradley, 1999; Chonjo, et al., 1996; Nyagura, 1995; Zezaguli 1999). Whilst Nyagura (1995) reports that most teacher trainees have inadequate or no training in the laboratory component of science education, Zezaguli (1999) reports that limited knowledge of alternative practical activities, lack of improvisation skills, and apparent negative attitudes towards practical work are among the barriers to successful laboratory teaching. Others have observed that teachers lack exposure to new methodologies of science teaching. In many countries there are shortages of regular in-service education activities (Chonjo, et al., 1996).

3.4.4 Examination focused practical work

Public (national) examinations have a strong influence on teaching and learning in most developing countries. In these countries practical work is mainly done to prepare students for final practical examinations. Addiction to national science practical examinations at the final stages of secondary school education has been reported as a very significant barrier to science education reforms in most developing countries (Allsop, 1991; Earnest & Treagust 2001; Ware, 1992). Allsop points out that such countries suffer from the usual defects and limitations of nationally set practical examinations. Obsession with final practical examination indirectly encourages many science teachers to include a minimum amount of practical work on those skills and techniques unlikely to be tested in the practical examination.

Ware (1992), on the other hand, argues that in countries whose curricula are examination driven, there is a high probability that if laboratory work is not tested practically it is not taught. In most cases, the examination system in these countries does not address the question of what the objectives of laboratory instruction should be and how achievement of these objectives can be measured reliably. Assessments in these countries tend to concentrate on student selection and certification, rather than focus on what does or does not work within the system and make appropriate adjustments. However, when such examinations are objectively used to assess students' performance in the laboratory they can motivate both teachers and students.

Although practical work is widely acknowledged in science curricula as an essential and integral part of science teaching, classroom realities in many countries, especially developing countries (including Tanzania), show that its implementation is difficult. There are many reasons why implementation of practical work is difficult, particularly in chemistry, but the main ones include: lack of equipment, limited teacher knowledge, skills, and confidence to do practical work, time pressures, and large class sizes. In view of these problems, micro-scale chemistry is a low cost approach to practical work in chemistry. It can help resolve some of these problems, especially those related to cost of equipment, preparation, large classes, and time pressures. In the next two sections (3.5 & 3.6) the potential for micro-scale chemistry education and the role of curriculum materials as support tools for teachers in implementing curriculum innovations in the classroom will be highlighted.

3.5 MICRO-SCALE CHEMISTRY: MEANING, BENEFITS, AND LIMITATIONS

Since the 19th century, instructional laboratories in chemistry were based on carrying out experiments with multi-gram quantities of materials. But into the 1980's, with continuing economic pressure in education and increased environmental awareness, the need to carry out practical chemistry on a much reduced scale, in order to save chemicals, time, and ease disposal problems became increasingly important. Until now micro-scale chemistry has been a part of laboratory practice and teaching, particularly at college and university levels (Towse, 1998; Ware, 1992; Zipp, 1989).

The term 'Micro-scale chemistry' refers to an approach or technique for carrying out experiments on a reduced scale using small quantities of chemicals and often (but not always) with simple equipment (Skinner, 1997). Micro-scale chemistry involves scaling down chemical reagents to volumes and masses one thousand times smaller than those used in traditional laboratories; and shifting from glassware to modern polymer or plastic materials in transfer, storage, and reaction devices (Bhanumati, 1997). Two distinct practices are also distinguished within the micro-scale chemistry concept. The first is based on the use of commercially made micro-scale chemistry kits, and the other is based on self-assembled apparatus. John Skinner from the UK provides an example of micro-scale chemistry based on self-made apparatus, and Merrimack College, Massachusetts, presents an example of micro-scale chemistry based on the use of commercially made micro-scale chemistry kits. The MSCE study is based on self-assembled micro-scale apparatus using materials that can be obtained locally and at an affordable price.

The movement toward micro-scale chemistry began initially as an attempt to reduce student and teacher exposure to hazardous chemicals and to minimize production of waste materials in the USA (Ware, 1992; Zipp, 1989). However, as teachers in schools and universities became more familiar with the equipment used in micro-scale experiments, and as 'traditional experiments' were modified for the new techniques, it became clear that there were many advantages to the micro-scale chemistry approach (Zipp, 1989). The economic and educational benefits of this approach are numerous and well-attested (Bradley, 1999; Rayner-Canham, 1994; Skinner; 1997; Towse, 1998):

- *Cost savings*: the cost of chemicals and laboratory equipment is greatly reduced, as is (in many cases) the need for dedicated laboratories and storage requirements.
- *Time savings*: preparation, experimentation, and clean-up times are greatly reduced. Thus, most micro-scale experiments can be performed more quickly than their larger scale analogues.

- *Improvement in laboratory safety and air quality*: with the use of small quantities of chemicals, the chances for fire, explosion, and serious injury is greatly minimized, as is the exposure to toxic chemicals.
- *Environment-friendly*: less waste is produced, and thus chemical disposal problems are virtually decreased. The micro-scale laboratory can be a less-cluttered, more comfortable place than the traditional laboratory because of micro-scale equipment.
- Beyond the economical, environmental, and safety advantages, micro-scale chemistry offers, a number of pedagogical advantages including the following:
- It engages students in hands-on learning experiences and provides more opportunity for collaborative learning;
- Students gain confidence in their own ability to work with small amounts of materials;
- Micro-scale experiments are much faster to carry out, allowing students to accomplish much more in the laboratory;
- Students enjoy it because the dullness usually associated with laboratory work is reduced since students are not sitting around and waiting for something to happen;
- It instils in students the ethics of resource conservation.

Despite the many advantages of micro-scale chemistry techniques, the approach has some limitations (Bradley, 1998, 1999). First, most of the micro-scale apparatus have temperature limitations as they are made from plastic materials. Heating of plastic equipment with a burner is not feasible. The second problem relates to the interaction of some chemicals with plastic materials. Many organic solvents and concentrated acids (e.g. nitric acid) cannot be used with the plastic items that predominate in the micro-scale chemistry apparatus. From these limitations, it is obvious that not all experimental requirements can be met with the micro-scale equipment. As a result, micro-scale chemistry experimentation forms an important part of practical chemistry, but it cannot be employed for each and every topic in the syllabus.

The benefits of micro-scale in the context of developing countries are exemplified by a small of studies only (Bradley, 2000; Sing et al., 2000, Thulstrup, 1999; Towse, 1998). The review by Towse (1998) on the microscale approach cites several studies (e.g. Bradley & Vermaak, 1996; Caro, 1995; Corley, 1995; Schultze, 1996) of high school students from different contexts in which strong positive attitudes toward microscale chemistry were exhibited. Among the findings from these studies are: enhancement of student laboratory skills, more focus on understanding of the concepts rather than on the manipulation of equipment, more time for questions, discussions and feedback, and more hands-on experience. Moreover, students find experimenting on a micro-scale easy and fun.

Empirical research on the impact of micro-scale chemistry on teaching and learning practices are limited. However, micro-scale chemistry techniques in teacher education colleges have shown a positive impact on both pre-service and in-service teacher education (Bradley, 2000). Bradley reports that both college and student teachers who used the micro-scale chemistry kits found that practical sessions were much easier than before, and students seemed interested. Bradley (2000) also reports that in a study undertaken to discover the attitudes of school teachers and students towards practical science on micro-scale and the extent to which learning of science concepts took place, the results were very positive. However, he notes that practical work showed very satisfactory knowledge gains where more competent teachers were involved (compared to less competent teachers). These findings show that the role of the teacher in facilitating student learning is crucial. Learning will not occur by simply engaging in practical work, whether micro-scale or macro-scale. Both pedagogical content knowledge and management skills are important on the part of the teacher for learning to occur also in a micro-scale setting.

Although many benefits of micro-scale chemistry in science teaching can be listed, empirical evidence of its impact on classroom practices and student learning, specifically at the secondary school level, appears to be very limited. The few studies that have been conducted have concentrated on investigating the economic aspects of micro scale methods in the conduct of practical work in school chemistry (Rayner-Canham; 1994, Sing et al., 2000; McGuire, Ealy & Pickering, 1991).

3.6 EXEMPLARY CURRICULUM MATERIALS TO HELP TEACHERS IMPLEMENT THE MSCE APPROACH

This section elaborates on the potential of exemplary curriculum materials as a support tool for implementing curriculum reform in the classroom. The MSCE study intended to design and evaluate a promising intervention for practical work in A-level chemistry education in Tanzania. Analysis of current practices (section 3.4) and the constraints of implementing practical work in secondary chemistry in Tanzania, as revealed in chapter 2 preparing and supporting teachers for carrying out the MSCE approach in the context of their classrooms is of vital importance. Thus to prepare and support teachers for the implementation of the MSCE approach in the classroom development of exemplary materials is considered a promising strategy (Ball & Cohen, 1996; Powell & Anderson, 2002; Schneider &

Krajcik, 2002; van den Akker, 1988). Along with teacher preparation, developing exemplary curriculum materials for translating the MSCE ideas in the classroom is considered as a necessity.

The role of exemplary curriculum materials

Implementing curriculum reforms is a challenging task. It requires change in practice. Teachers need to learn new classroom practices (and unlearn old ones). They will benefit from support in terms of 'what to do' and 'how to do it effectively'. Although curriculum materials have traditionally been designed with student learning as a goal, materials can be designed to support learning by teachers as well as students (Schneider & Krajcik, 2002). Likewise, curriculum materials have a role in helping to initiate and sustain reform in science education because they are concrete, tangible vehicles for embodying the essential ideas of a reform (Powell & Anderson, 2002). In this study, curriculum materials, a series of lessons designed on the basis of the Tanzanian A-Level chemistry syllabus are considered an important vehicle for exemplifying the use of the MSCE approach to support teachers in the implementation of practical work in A-level chemistry classes.

According to van den Akker (1988), exemplary curriculum materials should fulfil three main functions:

- provide clear understanding of how to translate curriculum ideas into classroom practice;
- provide a concrete foothold for the execution of lessons that resemble the original intentions of the designers;
- stimulate reflection on the teachers' role and any possible adaptations of the teachers' attitudes towards the innovation.

Investigating the role of curriculum materials in helping teachers implement a primary science curriculum, van den Akker (1988) identified four areas of implementation problems, each of which could be addressed with the help of exemplary curriculum materials. The first of these areas includes lesson preparation, which is often time-consuming and difficult. The second concerns the inadequate teachers' background knowledge and lack of confidence in subject matter and skills. The third relates the difficulty of changing the teacher's role—all the more difficult and time-consuming because it involves the alteration of teacher beliefs. The fourth involves monitoring student learning progress and outcomes, also considered a challenging task. In view of these aspects, van den Akker (1988) suggested creating materials with a large amount of '*procedural specifications*'. Procedural specifications are, according to van den Akker, clear and specific guidelines for that part of the intervention. These are apparently vulnerable when it comes to implementation, and where teachers might be uncertain. The outcomes of his study indicated that curriculum materials helped teachers in the initial phase of implementation by providing procedural specifications. Furthermore, his study concluded that carefully designed curriculum materials can improve the implementation process and outcomes.

Similar other studies involving development and use of curriculum materials in supporting curriculum reform efforts in secondary science education (in both developed and developing countries) have been reported (Ottevanger, 2001; Schneider & Krajcik, 2002; van den Berg, 1996; Voogt, 1993; Thijs, 1999; Tilya, 2003). Most of the findings from these studies are consistent with those reported by van den Akker (1988), but also provide an additional understanding, such as potential of curriculum materials in enhancing teachers' pedagogical content knowledge.

Schneider and Krajcik (2002) designed 'educative' curriculum materials, intended to support teacher learning as well as student learning. The materials incorporated information explaining science content for teachers beyond the level suggested for students; learning sets explaining the reasoning behind the sequence and flow of the lessons; short scenarios illustrating how an idea or activity may be introduced; help for using artefacts as assessment tools of the lessons; and notes to the teacher embedded within the lessons. Schneider and Krajcik found that teachers used the materials most during planning lessons for their students. They also found that through the use of the curriculum materials teachers learned about Pedagogical Content Knowledge (PCK) for the specific lessons.

Voogt (1993) designed and evaluated curriculum materials to support teachers in the use of courseware in an inquiry-based science curriculum in Dutch secondary schools. Whilst she found that teachers who used the teacher materials kept their lesson approaches closer to the intentions of the designer of the curriculum, teachers often used student materials for the preparation of their lessons. Voogt noted that teachers who used student materials performed considerably poorer in class than their colleagues who used teacher materials. Voogt concluded that when the discrepancy between the classroom routines of a teacher and the proposed intervention is too big, exemplary materials are in themselves not a sufficient aid for preparing and implementing the curriculum to a satisfactory level. The study by van den Berg (1996), on the other hand, indicated that the integration of materials with procedural specifications into an in-service programme helped to stimulate teachers to try new ideas in their classrooms and provides successful first-time experiences (cf. Ottevanger, 2001). Van den Berg also observed that inclusion of procedural specifications made lesson preparation less complicated and time consuming as compared to planning a lesson without them.

In the African context, especially Sub-Saharan Africa, several studies have successfully used curriculum materials as a strategy to support secondary science curriculum and teacher professional development efforts. Examples of these studies include those by Ottevanger (2001), Thijs (1999), Tilya (2003), Kitta (2004) Stronkhorst (2001). Ottevanger (2001) designed exemplary materials to help teachers implement a new science curriculum for junior secondary schools in Namibia. Ottevanger found that materials that incorporate procedural specifications on essential elements of the lesson provided adequate support for teachers in the initial phase of implementation of the new curriculum. Ottevanger reported also that the use of the materials as a part of in-service training programme enhanced effectiveness in supporting innovative reforms in science education.

Studies by Tilya (2003) and Kitta (2004) investigated the use of exemplary materials as a strategy to support science and mathematics teacher professional development in Tanzania. Outcomes from these studies were largely positive and were in line with the findings reported by similar studies carried out in Southern Africa (Ottevanger, 2001; Stronkhorst, 2001; Thijs, 1999).

Overall, research findings show that carefully designed curriculum materials have clear advantages. They serve as concrete examples to teachers on what it looks like when good teaching and learning materials go together with good classroom practices. The development and use of such materials is important as they also serve as cognitive tools to help teachers add new ideas to their repertoires (e.g., use of new and various teaching approaches and their rationales). More importantly, the studies show that exemplary curriculum materials containing a large amount of procedural specifications focusing on essential but apparently vulnerable elements of the curriculum can reduce teachers' initial implementation problems, and so enable them to conduct successful lessons. Exemplary curriculum materials with procedural specifications help orient teachers to the intended change and assist them in executing tasks they might have had difficulty with.

3.7 CONCLUSIONS AND IMPLICATIONS FOR THE STUDY

The previous sections have examined the role of practical work in science education from a variety of literature. The review has also explored the potential of micro-scale chemistry as a promising low-cost practical work approach in chemistry teaching in developing countries, especially sub-Saharan Africa. Despite the criticism of practical work, the research literature indicates that it can provide a potentially valuable learning environment for the achievement of some goals of laboratory teaching (Hofstein, 2004; Lunetta, 1998). According to Hofstein (2004), appropriately designed practical activities can be effective in promoting cognitive skills, practical skills, attitudes, and interest in chemistry and learning chemistry. In addition, providing students with authentic and practical learning experiences has the potential to vary the learning environment and thus to enhance students motivation to study chemistry. Apart from the above potentials of practical work, several issues resulting from this review seem relevant for the design and implementation of the MSCE practical activities. Such issues include clear identification of learning objectives, teachers' knowledge and skills, classroom convenience, incorporation of discussion and reflection, assessment of students' learning, and evaluating the effectiveness of students' practical work.

Limited and clearly specified learning goals

One of the major criticisms in the literature of laboratory-based science teaching is the lack of distinction between priorities and objectives of practical work. There has been a tendency to use practical work for each and every goal in science education (e.g., conceptual, process, and skill, all addressed at the same time) (Hodson, 1993; Lunetta, 1998). Without a clear understanding of the purposes of a practical activity, students do not seem to learn much from practical experiences. It has been suggested 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 it to students (Eijkelhof, 2002; Nakhleh, Polles & Malina, 2002).

Teacher knowledge and skills

Teachers' inadequate knowledge and skills of teaching in a laboratory learning environment have been identified as one of the main constraints to implementation of practical work in the secondary science curriculum in most developing countries (see section 3.4.3). This is also relevant for the Tanzanian context as revealed in the context analysis (see chapter 2). The literature provides enough indications that it is essential to equip teachers with both the content knowledge (CK) and pedagogical content knowledge (PCK). These knowledge bases are important for teachers to be able to enable students to interact intellectually as well as physically, involving 'hands-on' activities and 'minds-on reflection' (Bradley, 2000). According to Shulman (1986), CK refers to ones' understanding of the subject matter, and PCK refers to the ways of representing and formulating the subject that make it comprehensible to others. To successfully translate the MSCE approach into classroom practice and help students learn chemistry, teachers require adequate understanding of the (chemistry) theory behind particular micro-scale experiments (SMK), on how students can learn the chemistry content and need to be able to translate this understanding into appropriate plan for teaching particular topic to students (PCK). In addition to CK and PCK, teachers also need general pedagogical knowledge (ones' understanding of teaching and learning process independent of subject matter) in order to moderate students' discussion and reflections during the practical.

Practicality in the classroom

Besides teachers' competence, effectiveness of practical work in science and chemistry in particular is affected by other variables, such as class size, convenience and easy use of equipment. Convenience and ease of use of equipment and chemicals are considered important factors for promoting implementation of practical activities in chemistry because without it both teachers and students are likely to loose motivation (Bradley, 1998). Designing experiments with a simple set up and providing clear and concrete guidelines for carrying out experiments is considered an important aspect of the MSCE approach for enabling teachers to organize and conduct practical work in A-level chemistry teaching in Tanzania.

Incorporating discussion and reflection in practical lessons

Another crucial aspect of conventional laboratory work is the inadequate (or lacking) stress on student discussion and reflections, although such discussion appears to enhance effective laboratory learning (Lazarowitz and Tamir, 1994; Lunetta, 1998). As a result students have few opportunities to reflect on and develop their understanding of the scientific concepts underlying the activities they carry out. Based on this review, practical activities in the MSCE approach should be designed to get students to discuss (through small groups) the phenomena they observe during the practical experiences and to reflect on the meanings they deduce from such phenomena. These practical activities should not be ends unto themselves. Moreover, helping students link the data they obtain from the practical and the concepts being studied is considered an essential part of the intervention.

Assessment of students' learning in practical work

In order to bring about improvements in teaching and learning, it is essential that any assessment be aligned to the process of learning and teaching. However, classroom based studies indicate that in most African countries (including Tanzania) the curriculum is driven by the assessment demands rather than for understanding science (Allsop, 1991; Ware, 1992). Practical work is carried out mainly to prepare students for the national practical examinations. As a result, teachers limit their choices of experiments to those most closely related to the type of experiment covered in the examination (Hofstein, 2004). It is suggested that for effective practical work, apart from the summative assessments (national examinations), formative assessment involving observations, performance, written assignments, and oral questions needs to be incorporated into practically-oriented lessons to measure as many learning outcomes associated with practical experiences as possible.

Evaluating the effectiveness of practical work

It has been revealed that previous science education research in the educational effectiveness of practical work has had a limited focus in the sense that the value of practical work has been measured by comparison with other teaching approaches. Less focus has been directed toward what specific practical activities can achieve specific learning objectives. Four factors and their relationships have been suggested as crucial for determining the effectiveness of practical work in teaching and learning science (Millar, et al., 1999):

- *learning objectives (teachers' or curriculum developer's intentions)*: specifying what students are supposed to learn from the practical work;
- *design features of the activity*: representing the type of activities students are supposed to do, when they are supposed to do it, and with what resources;
- *classroom actions*: what students actually do (are able to do);
- *student learning*: what students actually learn from the activity.

According to Millar et al. (1999), both the objectives and the task design are influenced by teachers' views of science (ideas about what is important to teach) and learning (ideas about how students learn), and by the practical and institutional context in which the practical takes place (such as the resources available, the requirement of the curriculum, its mode of assessment). Similarly, both the actual classroom actions with and the student learning from the practical are influenced by students' views of science (e.g., interest in the subject) and learning (ideas about how one learns) and institutional realities and context of the task (time available, importance of the task in relation to achieving success in the course). Millar et al. (1999), suggest that the effectiveness of practical work should first be looked at regarding the extent to which actual classroom practice matches what the teacher or curriculum developer intends. Second, how the students' actual learning corresponds to the intended learning outcomes. They argue that at both levels teachers' and students' ideas about science and learning science must be taken into account.

CHAPTER 4
Design and formative evaluation of exemplary curriculum materials

This chapter focuses on the design and formative evaluation of exemplary curriculum material prototypes for micro-scale experimentation in Tanzanian A-level chemistry teaching. Guided by a development research approach, evolutionary prototypes were created in a series of subsequent design, formative evaluation, and revision steps. Section 4.1 introduces the chapter with an overview of the context and aim of the MSCE study. To guide the development of prototypes, design guidelines were formulated (section 4.2). In section 4.3 the overall development process of prototypes is described. Sections 4.5 and 4.6 present the trials and appraisal of the second prototype by both the school teachers and university science student teachers. The results of the trials are described in section 4.7. The third cycle of formative evaluation involved an appraisal of the third prototype by a panel of experts. The procedure and results of an expert panel session are presented in section 4.8. Conclusions and implications for further development are summarized in section 4.9.

4.1 INTRODUCTION

The MSCE study aimed at designing and evaluating micro-scale chemistry practical activities for the A-level chemistry curriculum that are simple to conduct and affordable to obtain within given resource constraints. The context analysis (chapter2) and the literature review (chapter 3) provided background information out of which important design guidelines and initial design specifications for the teacher support materials were formulated. The context analysis provided a clear image of the current status of secondary science education in Tanzania. From the context analysis, several constraints to implementation of chemistry practical work in secondary schools were identified, including: limited equipment; inadequate teachers' knowledge and practical skills; shortage of textbooks and laboratory guides; large class sizes; time pressure due to syllabi overload and examination demands. Findings from the literature study revealed similar images of practical work in secondary science education for most developing countries, especially in sub-Sahara Africa. Apart from pointing out the current practices in the conduct of practical work, the literature review provided some important ideas for designing effective practical work (Eijkelhof, 2002; Lazarowitz & Tamir, 1994; Millar, et al., 1999). More importantly, the literature review highlighted the potential benefits of micro-scale chemistry that could contribute to improving implementation of chemistry curriculum, in particular, provision of practical work in Tanzania secondary schools. This chapter focuses on the design and formative evaluation of exemplary curriculum materials developed to support teachers with the initial classroom implementation of the MSCE approach in Tanzanian A-level chemistry classes. The materials are designed and evaluated for the topic of *solubility* and *precipitation*, which is part of the Tanzanian Chemistry syllabus for Form 5 and 6 students. To focus the development of the materials seven design guidelines were formulated and they are outlined in the next section.

4.2 DESIGN GUIDELINES FOR THE MSCE EXAMPLARY LESSON MATERIALS

In view of the information obtained from the context analysis and literature review, the following preliminary guidelines were formulated to guide the design and formative evaluation of lesson prototypes for MSCE approach.

1. *Active learning through micro-scale chemistry experimentation*
   - Focusing on student-centred approaches and learning for understanding, exemplary curriculum materials are designed to involve students actively in the learning process through both hands-on and minds-on practical work. The MSCE practical activities are designed with more emphasis on manipulation of ideas rather than manipulation of the equipment.
2. *Simple forms of practical work*
   - Practical activities designed with MSCE approach are simple to carry and do not depend on an expensive science laboratory. It uses simple equipment mostly obtainable in local environment and can be achieved with a minimum amount of chemicals.
3. *Science (chemistry) learning goals*
   - Specification of the intended learning outcomes the designer (or teacher) has in mind for students is an important factor to designing effective practical work (Eijkelhof, 2002; Millar et al., 1999). To support teachers with the implementation of MSCE approach, exemplary curriculum materials are designed with clear and few learning objectives for a given practical task.

4. *Content and pedagogical support*
   - Reflecting on the challenges Tanzania secondary chemistry teachers' face in terms of content and pedagogy as revealed in the context analysis (section 2.4.1), exemplary curriculum materials intended to support teachers with the implementation of the new approach are designed with adequate support for content and teaching strategies; particularly in:
     – lesson preparation;
     – practical work;
     – group work;
     – assessment of student learning.
5. *Alignment with current curriculum*
   - Exemplary curriculum materials designed and developed must support the teaching and learning of the existing curriculum. Materials that do not fit into the existing curriculum are likely to make teachers loose interest and adopting the new approach for use in their teaching might be difficult. Users (teachers) of the materials must believe that the materials will become part of the established curriculum and that it is not a waste of time. In this way legitimacy of the new approach can be established.
6. *Fit with the school time table*
   - Exemplary curriculum materials are designed with lesson activities that can be carried out within periods allocated for practical work (2-4 periods of 40 minutes each) prescribed for the Tanzanian A-level science curriculum.
7. *Flexible and active learning environment*
   - Exemplary curriculum materials should provide flexibility for teachers to integrate theory and practical work easily and promote more interaction among students and between students and their teacher through small group discussion.

4.3 DEVELOPMENT OF PROTOTYPES

Design and formative evaluation of prototypes

The development of prototypes in the MSCE study employed a prototyping approach. According to Nieveen (1999) prototypes are all products that are designed before the final product is constructed and fully implemented in practice. In developing exemplary curriculum materials (i.e. teacher support materials and student worksheets), a succession of prototypes were created in an evolutionary prototyping approach. The development process involved a series of subsequent design and formative evaluation and revision steps of prototypes (see Figure 4.1).

The first version evolved from the design guidelines and specifications of exemplary lesson materials and was appraised by three experts. On the basis of revision decisions made on the first version, the second version was developed and used in a classroom try-out by three teachers and their students. In addition, this version was tried out and appraised by 76 undergraduate science education students during their final year of a chemistry methods course at the University of Dar es Salaam, in Tanzania. The third version was developed and appraised by 5 experts in an interactive panel session. This phase resulted in the fourth and final version. The results of evaluation of each preceding version were used in the development of the next version. Figure 4.1 illustrates the development process of prototypes.

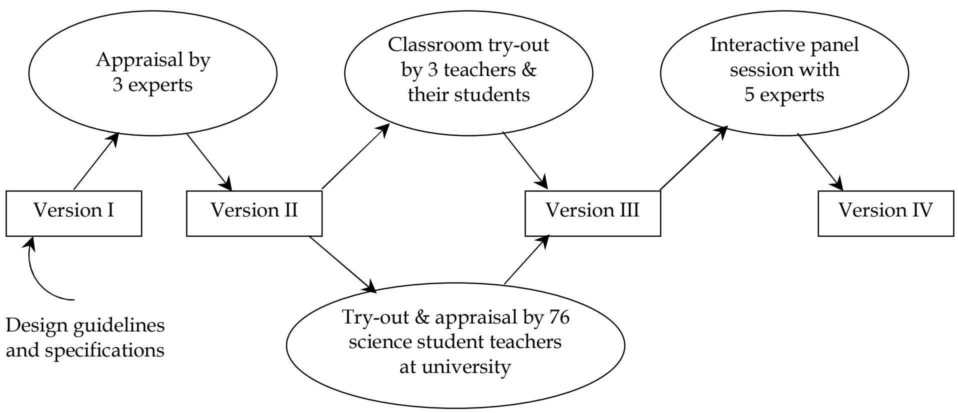


Figure 4.1 The development process of prototypes

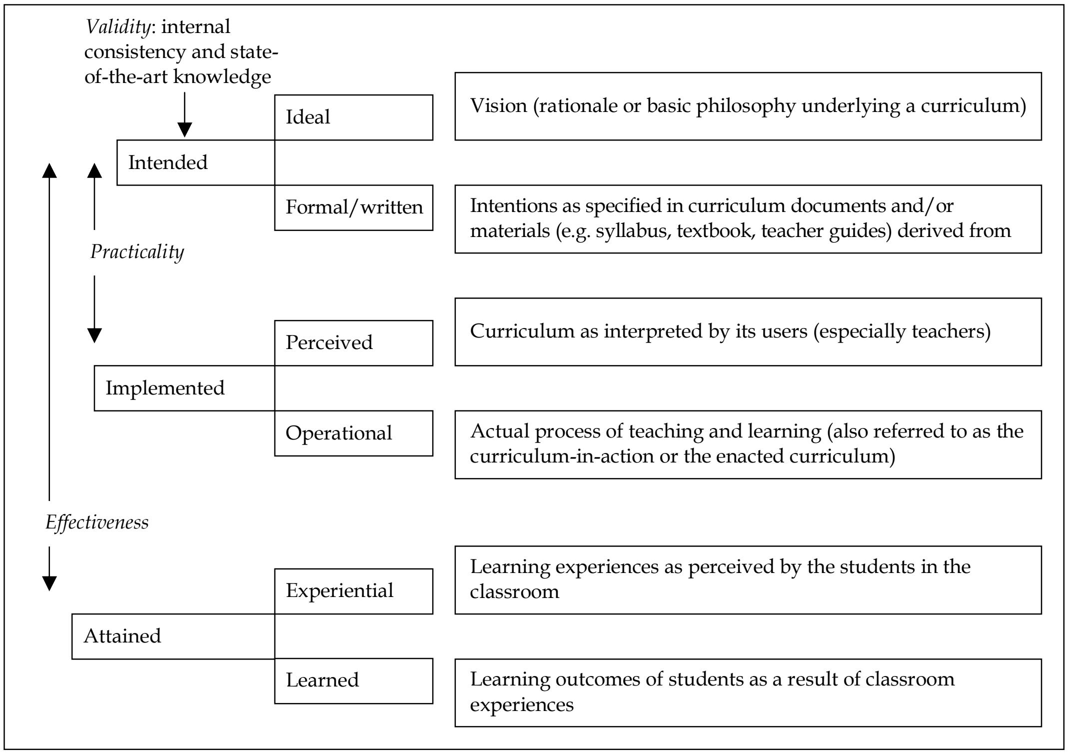
Quality focus of prototypes

In developing each of the four prototypes (versions I to IV) the main focus was to increase the quality of the prototype as the development progressed. The quality of a prototype refers to its validity, practicality and effectiveness (Nieveen, 1999; van den Akker, 1999):

- *Validity* refers the extent to which the design of the intervention is based on the state-of-the art knowledge (content validity) and that the various components of the intervention are consistently linked to each other (construct validity).
- *Practicality* refers the extent to which users (and other experts) consider the intervention as appealing and usable in 'normal' conditions.
- *Effectiveness* refers to the extent that the experiences and outcomes with the intervention are consistent with the intended aims.

The three aspects of quality can also be linked to the typology of curriculum representations as distinguished by Goodlad, Klein and Tye (1979), and elaborated van den Akker (1998, 2003, see Box 4.1).

Box 4.1 *Typology of curriculum representations taken from van den Akker (2003) and its quality criteria for good quality materials adapted from Nieveen (1999)*



Box 1 illustrates both the broad and refined distinctions of various levels of curriculum representations. These include *intended* (ideal plus formal) curriculum; the *implemented* (perceived plus operational) curriculum and the *attained* (experiential plus learned) curriculum. The validity aspect focuses on the curriculum materials itself (the intended curriculum) and is attained when its various components are based on the state-of-the-art-knowledge and all components are consistently linked to each other. *Practicality* of the materials is related to the consistency between the intended and implemented curriculum. In this respect, practicality is attained when the materials are usable by the teachers and students in ways that match with developers' intentions (i.e., if consistency exits between the intended and perceived curriculum as well as between the intended and operational curriculum). The third criteria, effectiveness, is indicated when students appreciate the learning approach (in this case, the MSCE approach) and that desired learning takes place (the long arrow on the left of Box 4.1). The approach is effective if consistency exists between the experiential and intended curriculum on one hand, and on the other hand between the learned and intended curriculum.

In the design and formative evaluation of prototypes as illustrated in Figure 4.1 the emphasis was on obtaining information for improving validity and practicality of the exemplary curriculum materials and the MSCE approach, which is addressed in this chapter. The effectiveness of the MSCE approach was the focus of the summative evaluation stage and is dealt with in chapter 5.

4.4 THE DESIGN AND APPRAISAL OF THE FIRST PROTOTYPE

4.4.1 Design

The first version of teacher support materials was developed by the researcher. On the basis of the design guidelines described in section 4.2, the development of materials adapted the design specifications used by similar studies done in Namibia (Ottevanger, 2001) and Swaziland (Coenders, 1995). Materials designed from these studies focused on supporting teachers by providing *procedural specifications* (i.e. very concrete how-to-do-it advice) in the areas of lesson preparation, subject matter knowledge, teaching methodology (pedagogy), and assessment of student learning. The general format of the exemplary curriculum materials in the MSCE study included these features with an addition of a general introduction of the prototype to the teacher, referred to as *explanation for the teacher*. Therefore, the first version of teacher support materials consisted of explanations to the teacher, exemplary lesson materials for teachers and student worksheets. Explanation for the teacher provided an overview of the exemplary materials including the topic, its place in the syllabus, and the target group (grade level) for which the materials are designed and developed. It introduces the teacher to the micro-scale chemistry approach as the focus of the materials. Also this part provides the sequence and content of lessons as well as summarizing the general issues of preparation and execution of practical lessons. The exemplary lesson materials contain procedural specifications to support teachers in executing micro-scale chemistry practical activities in their classes. Table 4.1 provides an overview of the design specifications used to develop the prototypes of teacher support materials in the MSCE study.

Table: 4.1 *Design specifications of exemplary teacher support materials*

Area of support	Design specifications
Lesson preparation	*General description of lesson* ▪ Description of what the lesson looks like: provide the general overview of the lesson. ▪ Objectives of the lesson: indicates learning outcomes expected to be achieved by the students at the end of each lesson. ▪ References to resources for further reading: suggests possible textbook and chapter that teachers can refer for more content information and student assignments. *Lesson preparation* ▪ Lesson plan and timing: suggests time for each lesson stage and the learning activities. ▪ Materials required for the lesson and possible alternative if not available ▪ Specific information on reagents preparation ▪ Necessary safety precautions on toxic chemicals ▪ Possible problems (and how to deal with) students may encounter during the lesson
Subject matter and pedagogical content knowledge	*Subject content* ▪ Suggestions for questions for pre-lab exercise to help teachers explore students' prior knowledge and to provide students with an idea about the practical they are going do. ▪ Adequate and accurate notes on what students are expected to be taught and learn. ▪ Examples of students' questions and answers. ▪ Short explanation of key chemical concepts in the lesson.
Teaching methodology (pedagogy)	*Teaching strategies* ▪ Concrete suggestions for the role of teacher during lesson execution. ▪ Suggestions for grouping: to guide teachers in using groups for practical work and small group discussion to promote student active participation in the lesson. ▪ Suggestions on how to hand out equipment and how to collect them. ▪ Suggestion on how to try-out experiments beforehand: to ensure reagents are functioning well for a particular experiment. ▪ Sequencing of learning activities, including pre-lab and post lab discussions.
Assessing student learning	*Learning effects* ▪ Suggestions for data analysis and concept development questions, small group presentations and test questions. ▪ Suggestion for homework questions.

Applying these design specifications four exemplary lessons of 80 minutes duration or two periods of 40 minutes each) were developed for the first prototype. A summary of these lessons is presented in Table 4.2.

Table 4.2 *Summary of exemplary lessons in the first prototype for teacher support materials*

Lesson	Description of lesson
1	*Introduction to solubility and precipitation*: In this lesson, students' understanding of basic concepts used in solution chemistry, such as solute, solvent, solution, ions, cation and anion, is explored through a pre-laboratory exercise and discussion. The main part of the lesson involves two demonstration experiments to explore the concepts of dissolution and precipitation, and introduce students to micro-scale chemistry experimentation. The experiments involve reaction between lead nitrate and potassium iodide under two conditions, in solid and solution form; and the dissolution of potassium permanganate in water.
2	*Investigating solubility of some common salts in water*: In this lesson students perform several experiments applying micro-scale techniques to test the relative solubility of some common salts in water. Solutions of 17 salts have been prepared. Five of the salts have a common *cation*, sodium (Na^+). The other twelve salts have a common *anion*, nitrate (NO_3^-). Pairs of solutions are mixed (one drop from each solution) on a plastic sheet, reactions are observed and recorded on a prepared grid paper and analyzed to generate a solubility table for some common salts. Solubility rules of some common nitrates, chlorides, hydroxides, and sulphates of group 1, 2 and 3 metals are established based on experimental results.
3	*Applying solubility rules to identify unknown ions in solutions:* This lesson introduces students to qualitative analysis of ionic compounds. Students are confronted with a problem of misplacing labels of eight chemical solutions. They perform an experiment to identify the correct label of each solution using the micro-scale approach. With the aid of solubility rules and the list of known solutions, students compare observations of known and unknown solutions to determine the identity of each chemical.
4	*Solubility product constant*: This lesson is about discussion and demonstration experiments concerning equilibrium constant for sparingly soluble solids or *solubility product (*K_{sp}). It is mainly a theory lesson that incorporates some aspects of practical work done as teacher demonstration to help students grasp the meaning of *ion product* (Q) and its relationship with K_{sp}, as well as the conditions for precipitation reactions to (not to) occur. The learning activities in this lesson include description of K_{sp}, determination of the value of K_{sp} from molar solubility data and vice versa, prediction of precipitate formation using K_{sp} and Q.

Lesson two of this prototype (and in the subsequent prototypes) constituted the major part of the prototype that applies the micro-scale chemistry experimentation approach. Part of this lesson is presented in Box 4.2 and 4.3 to illustrate some typical characteristics of the materials.

Box 4.2 *Teacher support materials*

LESSON 2: Exploring solubility of some common salts in water (Double lesson)

6. Lesson plan and timing

Activity	Approximate time (in minutes)
Introduction	10
Execution of the lesson (activity 2.1-2.4)	60
Conclusion	05
Ending the lesson	05
Total	**80**

7. Execution of the lesson

Introduction *(10 minutes)*

Begin the lesson with a pre-lab exercise. Students individually answer short questions related to the experiments they are going to perform for the purpose of engagement. The exercise also serves as a revision of key chemistry terms and concepts encountered in lesson 1.

Collect and summarize student answers on the blackboard. Briefly, go through each question with students to check possible areas of difficulties or misconception and make correct explanations. Link the explanations on the exercise to the students' practical work.

Prepare students for the following activities (activities: 2.1-2.3) by organizing them in small groups (2- 3 students per group). Assign specific roles to members in the group, e.g., chair person, recorder, and materials' manager.

Activity 2.1: Student Practical (30 minutes)

Use one pair of solutions ($AgNO_3$ and NaCl) as an example to demonstrate how this activity should proceed.

- Show students the position of $AgNO_3$ and NaCl on the reaction grid sheet.
- Show solutions of $AgNO_3$ and NaCl for students to note the colour of solutions. Ask students to predict what will happen when they are mixed? Write answers on the chalk board.
- Mix the two solutions (1 drop from each solution) on the appropriate square in the reaction grid over the plastic sheet:
  - ask students: what did they see happening? (possible answer: *a dense white precipitate*)
  - guide students to identify all ions present in the mixture, identify possible products, and identify the insoluble product.
- Direct each group to collect solutions of cations and anions (*students MUST note the colour of each solution before mixing*)
- Each group mixes drops of solution over the plastic sheet (*see student practical guide)* and carefully observes and records what happens on the data sheet using the second copy of the reaction grid.

Box 4.2 (continued) *Teacher support materials*

Activity 2.2: Group presentation and discussion (15 minutes)

- *Guide groups to compare their observation notes and note down their differences*
- *Ask representative of few groups to report the results to the whole class.*
- *Discuss group results with students. Some discussion points could be:*
  - i. *when do precipitates form? (Form only when an insoluble product results from the combinations of ions in solutions)*
  - i. *why the precipitate could not be formed, for example, in the first row? (Because both products are very soluble in water)*
  - ii. *how can the formation of a precipitate be represented by a net chemical equation?*
- *Use the questions below to guide students formulate some generalizations regarding solubility of some common salts in water. From your observations:*
  - i. what property do all compounds containing NO_3^- have?
  - ii. when are sulphates not soluble?
  - iii. when are chlorides and iodides not soluble?
  - iv. when are carbonates and hydroxides soluble?
  - v. Form a rule based on your observations of the solubility of salts containing anions: nitrates, chlorides and iodides, sulphates, hydroxides and carbonates.

Activity 2.3: Checking class generated solubility rules (10 minutes)

After discussing student data and creating a set of generalizations regarding solubility of certain ionic compounds (e.g. compounds containing SO_4^{2-} , Cl^-, NO_3^-, and OH^-).

- Call attention to the "solubility rules" in the textbook or any other source, or distribute a copy of the textbook (see lesson summary by the teacher). Compare these two sets of "rules."

Spot check student understanding by posing questions on possible combinations of solutions. (*What would happen if solutions of lead nitrate and potassium carbonate were mixed*? *What would the precipitate be?)*

Box 4.3 *Student worksheet*

Table2.1
Grid for mixing solutions (inserted in an A4 plastic sheet)

Aqueous solution of	**$NaNO_3$**	**NACL**	**NaI**	**Na_2SO_4**	**NaOH**	**Na_2CO_3**
$NaNO_3$						
KNO_3						
NH_4NO_3						
$AgNO_3$						
$Ca(NO_3)_2$						
$Ba(NO_3)_2$						
$Pb(NO_3)_2$						
$Cu(NO_3)_2$						
$Al(NO_3)_3$						
$Fe(NO_3)_2$						
$Mg(NO_3)_2$						
$Zn(NO_3)_2$						

Data analysis and concept development

1. Observe the patterns in precipitation (table 2.1). What conclusions can you draw regarding the solubility of various combinations of ions in solution?
2. Which of the following pairs of ions should produce a precipitate in water solution? Give reasons for your choice.
   a. $Ag^+ + CO_3^{2-}$ d. $Al^{3+} + Na^+$ g. $Ag^{2+} + Cl^-$
   b. $Mg^{2+} + OH^-$ e. $Al^{3+} + CO_3^{2-}$
   c. $K^+ + SO_4^{2-}$ f. $Pb^{2+} + I^-$

4.4.2 Expert appraisal

The purpose of the appraisal was to explore the validity of lesson materials prototypes. This was achieved by gathering views of science education experts with ample experience in chemistry pedagogy and in the development of curriculum materials.

The first prototype was appraised through individual expert consultation. Three international science educators were consulted individually to give their appraisal. All three experts were working collaboratively with Tanzanian science educators in different science education projects focusing on improving science teacher education in Tanzania. After being developed, compiled and typed, the lessons were given to experts for initial formative feedback regarding the quality of the materials. Aiming at ascertaining the validity of the materials the experts were asked to look at both teacher support materials and student worksheets and provide comments on the various aspects of the materials, such as layout, the content, presentation and timing of learning activities, set up of experiments and the use of chemistry language and student assignments.

In general, all experts commented positively on the idea of micro-scale experiments intended for student practical work and the layout of the materials. They commented that the content and learning activities were structured to adequately achieve formulated learning objectives. They also commented on some of the questions for students as challenging and good for group work and for homework assignments. However, the experts also observed some aspects which needed attention for improving the prototype. Experts indicated that the time estimated for some activities, such as introduction and small group presentations were not enough and needed revision. In addition to lesson timing, the experts suggested to add more procedural aspects in the materials which would provide teachers with more hints on how to involve students actively in the lesson. On the content of student worksheets, the experts indicated that the summary given in lesson 1 gave away all the answers to the questions students were to answer during the lesson as well as for the homework. Likewise, the experts noted that there was a mismatch in the description of the experiments between the teacher support materials and student worksheets. In the teacher materials experiments were described as teacher demonstration while in the student worksheets they appeared as student own experimentation. The experts suggested that clear instructions should be given in the student worksheet to distinguish between experiments intended for teacher demonstration and experiments for students to do themselves. After receiving the comments from the experts, the first version was revised incorporating all the necessary corrections and suggestions. The revision of the first prototype comprised the first cycle of formative evaluation and resulted into the second version, which was used in the classroom try-out.

4.5 CLASSROOM TRY-OUT OF THE SECOND PROTOTYPE

The second cycle of formative evaluation activities involved try-out of the second version of prototype lesson materials with teachers and their students in the classroom. Like in the first cycle this version consisted of four lessons (1 to 4) and had similar characteristics as the first prototype but incorporated results from the appraisal of the first version by experts. The main aim of the try-out was to explore the validity and practicality of the MSCE approach in the context of Tanzanian A-level chemistry classes. It specifically intended to find out whether teachers were able to use the exemplary materials to implement the MSCE approach with their students in class as intended by the designer. The try-out also intended to find out whether the approach engaged students actively in the learning process.

4.5.1 Participants: teachers and students

The try-out was conducted in two urban government schools (here referred to as school 1 and 2) from Dar es Salaam region. School 1 is a girls' school consisting of both Ordinary and Advanced Levels. School 2 is a co-educational institution offering A-Level only. These two schools were both government secondary schools with a science stream. Table 4.3 provides a summary of the characteristics of the participants in the classroom try-out of the second prototype.

Table 4.3 *A summary of characteristics of participants of the try-out*

	Schools		
Participants	*School 1*		*School 2*
Teachers	T1	T2	T3
▪ Gender	Female	Male	Male
▪ Professional qualification	B.Sc. (Ed), Diploma (Ed.)	B.Ed. (Science), Diploma (Ed.)	B.Ed. (Science)
▪ Teaching subject	Chemistry	Chemistry	Chemistry
▪ Teaching experience (years)	18	25	4
▪ Other responsibility	-	Head of department	Head of department
Students			
▪ Level (Form)	A-level, Form 5		A-level, Form 6
▪ Age range (years)	18-21		18-23
▪ Number of classes	2		2
▪ Number of students	56 (30 PCB, 26CBN)		46 (22 PCB, 24 PCM)

Note: CBN, PCB & PCM refers to subject combinations of: Chemistry, Biology & Nutrition; Physics, Chemistry & Biology, and Physics, Chemistry & Advanced Mathematics.

As presented in Table 4.3 the participants were A-level secondary school chemistry teachers and science students. Three teachers (two from School 1 and one from school 2) and students from two classes at each school constituted the participants of the try-out. Teachers from school 1 (T1 and T2) were well-qualified (possessing B.Ed/ B.Sc. Ed degrees and teaching diplomas) with extensive teaching experience as chemistry teachers. The third teacher (T3 from school 2) was also well qualified (possessing a B. Ed degree) and had a teaching experience of four years. Teachers from school 1, T1 and T2 had also experience in developing materials for the secondary school chemistry curriculum. Teachers T2 and T3 were heading their chemistry departments in their respective schools.

A total of 102 (28 boys and 74 girls) students in the two schools took part in the try-out. Participating students from both schools were studying chemistry as one of the main subject in their A-level program. Students from school 1 were in their first year (Form 5) of A-level secondary education programme and registered in PCB and CBN subject combinations, while students from school 2 were in the second year (Form 6) from PCB and PCM subject combinations.

4.5.2 Instruments

The instruments developed for use in the try-out were adapted from the instruments that were used in a similar study (Ottevanger, 2001). These instruments included a teacher evaluation questionnaire and interview, student questionnaire and interview, and the researchers' logbook. These instruments are described in the following sections.

Teacher evaluation questionnaire and interview

Three teachers (two from school 1 and one from school 2) completed the evaluation questionnaire at the end of all sessions with micro-scale chemistry practical lessons. Each teacher completed the questionnaire individually. The questions for the teachers focused on the teachers' general impression about the materials and practical activities (relevance, content, structure and presentation); aspects of the materials they liked (disliked) most; possible problems related to timing of lessons; availability of suggested materials for micro-scale practical activities and possible safety problems; and other observed practical problems during lesson execution in class. Teachers were also asked to provide alternative suggestions and how they could adapt the MSCE approach in their schools or classes. After each teacher had returned the questionnaire, teachers' responses were pooled together and analyzed. Based on the results of the questionnaire, a follow-up open-ended interview with two teachers (one from each school) who had their classes participating in the tryout was conducted on appointment to elicit in-depth information and clarifications on some aspects of the materials as revealed from the questionnaire results. For detailed information about these instruments see Appendices A1 & A2.

Student questionnaire

37 students from school 1 and 21 students from school 2 completed a semi-structured questionnaire at the end of all lesson sessions. The questions were aimed at finding out views and experiences of students about the practical lessons they carried out using micro-scale chemistry approach. The questions focused on what things they liked (disliked) most about the lessons with micro-scale approach, about specific learning activities they carried out and how the lessons compared to their regular chemistry classes. In attempt to solicit more thoughtful and focused responses, questions were structured in such a way that only two answers could be provided. In addition, students were required to provide a reason or an explanation for each response they gave. The student questionnaire can be found in Appendix A3.

Student interview

A group of ten students from school 1 participated in a focus group interview. The interview took place one week after implementing micro-scale chemistry practical lessons. The interview schedule was semi-structured, with some questions expanded to include more follow-up questions to get more insights of the students' views and experiences about learning solubility and precipitation with micro-scale experimental approach. The student interview was audio-taped and notes were taken at the same time. The interview conversations were transcribed and summarized according to questions in the interview schedule. The student interview schedule can be found in Appendix A4.

Researchers' log book

The researchers' log book was used to maintain a record of activities and observation notes associated with the use of the MSCE curriculum materials by teachers during the introductory and lesson preparation sessions and in the classroom with students. The field notes were kept mainly on the difficulty parts of the materials teachers experienced during the preparations and their suggestions for improvements. On lesson execution, running notes were kept on the way teachers introduced the new approach in the classroom, how they monitored student participation in the activities and the learning progress. Also the notes were kept on the observed general response of students to performing chemistry experiments on micro-scale and difficulties they encountered.

4.5.3 Procedure

For the formative evaluation of the exemplary lessons, three out of four lessons from the second prototype were used in the try-outs. These lessons included an introductory lesson (lesson 1), a full practical lesson (lesson 2) with micro-scale approach and a theoretically oriented lesson (lesson 4).

In preparation to the try-out the researcher distributed copies of both teacher support materials and student worksheets one week before meeting with teachers in a preparation session. The try-out process involved interactive preparation sessions (a half day in-house orientation workshop) with teachers and the researcher at each school to introduce them to the materials and the purpose of the study being carried out. Activities in these workshops included preparation of reagents, trying out the experiments in advance with teachers, and preparation of student practical work. The use of materials in class with students at each school is described in the next sections.

School 1

At this school two practical lessons (1 and 2) were co-conducted in two sessions by two teachers with the researcher as facilitator and participant observer. The third session involved general discussion with students about the experimental results and difficulties they encountered in carrying out experiments using the micro-scale approach. This session was facilitated by one teacher and the researcher. At the end of the discussion a semi-structured questionnaire was administered to students to find out their views about the practical lessons they did using micro-scale chemistry techniques.

School 2

At this school the interactive preparation session was held between one teacher and the researcher. The second teacher that was identified for the study had a special assignment outside the school. Due to the tight time table and mock examinations for the participating students, the teacher was able to try-out only one lesson. Based on the experiences obtained from school 1, lesson 2 was chosen because it contained a larger part of experiments demonstrating the use of micro-scale chemistry approach compared to the three other lessons. This lesson was tried out in two classes. The first class involved Form 5 students and the second class involved Form 6 students. The two lessons were co-supervised by the teacher and the researcher as a participant observer. The second meeting for each class involved general discussion with students and reflection on the various aspects of the micro-scale experiments such as involvement of members within the group and difficulties encountered in carrying out the practical activities. The last activities involved administration of a semi-structured questionnaire to students about their experiences and opinions about the practical activities carried out on micro-scale.

As stated earlier, the main purpose of the try–out was to get formative feedback from users about the practicality of the MSCE approach in the real classroom conditions. Therefore teachers were requested to execute the lessons, making use of the materials not as finished products, but as products which are in the process of development and could further be improved. At this stage of development of prototypes the researcher was interested in how teachers were able to translate the idea of micro-scale practical activities into their classroom practices and in generating additional ideas for further improvement of the materials. Teachers were therefore encouraged to offer alternatives wherever they felt an improvement was needed, but paying attention to the new teaching approach and its goal to promote both "hands-on and minds-on" practical work. By allowing flexibility among teachers it was hoped that the try out could provide insights in the feasibility of MSCE approach as well as additional ideas for the lesson materials, which could be incorporated in the next version.

4.6 TRY-OUT AND APPRAISAL BY STUDENT TEACHERS

A second try-out involved the use of the exemplary materials by 76 final year science education students at the University of Dar es Salaam who were prepared to become A-level chemistry teachers. Part of their course involved analysis of the Tanzanian A-level chemistry syllabus and problems associated with its implementation. Before the try-out, students had participated in three teaching practices, including teaching chemistry at A-level schools. Therefore the try-out and appraisal with this group intended to get feedback on the validity and usability of the MSCE approach from potential users (chemistry teachers) of the exemplary materials. As part of their course, students participated in 4 sessions (3 contact hours per sessions) involving introduction to the micro-scale chemistry approach (lesson 1 in the material), MSCE practical activities (lesson 2 & 3), and general discussion of the MSCE approach. The practical activities were carried out in groups of 5 students. It was not feasible to conduct practical work in groups of 2 to 3 students as suggested in the materials because of the large class and limited space of the laboratory. During the execution of the experiments small groups compared and discussed their results. The lesson sessions were supervised by the course lecturer and the researcher. In the last session the researcher held discussions with the students about the lesson activities and the MSCE approach. The focus of the discussion was on students' opinions about the practical activities they carried out using micro-scale approach; usability of the approach and aspects of the approach students felt needed improvement. During the discussion one member from the students and the researcher took notes of the discussion. After the discussion notes were compared and summarized by the researcher.

4.7 RESULTS OF THE TRY-OUTS

The try-outs focused on how the practical lessons with the MSCE approach were executed in class, how the teachers felt about using the materials and the new approach to conduct practical activities in their classes and what the students experienced about lessons done with the MSCE approach. The results of the try-outs are presented in sections 4.7.1 – 4.7.4.

4.7.1 Initial impressions of teachers on micro-scale chemistry experimentation

In general, all three participating teachers were very positive about the teaching materials supporting them with the implementation of the micro-scale chemistry practical activities in their classes. They raised some few aspects of the materials to be looked at, e.g. on concepts in the syllabus but missing in the materials, but generally they felt that the materials presented the subject matter in a clear and simple structure, yet with a lot of learning activities for students. Some specific responses from teachers on the support materials are summarized in Table 4.4.

Table 4.4 *Teachers' general impression about the support materials prototype and the MSCE approach*

Aspect of the materials	Teacher 1	Teacher 2	Teacher 3
Relevance and usability	Very useful: provided a short way of determining solubility of different substances with few and simple apparatus.	Very helpful in the teaching the concepts of soluble and insoluble salts.	Very relevant for A-Level students: uses experimentation as the main method of teaching. The materials provide students with enough opportunity to perform experiments make observations and discuss the results.
Content of the lessons	Contain all the necessary contents.	Cover well some topics of O-Level and A-Level Chemistry.	Covers important contents as specified in the syllabus, but a few concepts are missing*.
Structure of the lessons	Not complicated. It is easy to follow. Experiments uses few and simple apparatus	The content is well presented. Experiments are well explained and the follow-up questions are well understood.	Good: concepts are clearly presented.
Lesson timing	80 minutes would be enough provided that students' guides are given a day in advance	Lessons can take shorter time if student instructions are given in advance	80 minutes are enough but 15 minutes would be better than 10 minutes for introduction
Type and availability of equipment	All materials for the experiments can be obtained at cheap price.	Equipment for the experiments can be purchased locally at cheap price	It is difficult to get the plastic sheets as the school is not used to buy this kind of apparatus
Adaptability of materials in own school or class	By conducting micro-scale practical work before starting theory lessons on solubility so that students can use their experiences to learn the concepts.	By using micro-scale experiments in teaching solubility rules to O-level students and teaching solubility and precipitation to A-level students.	By encouraging the use of plastic sheet during normal practical sessions

Note: * Teachers' suggestion on missing concepts: - factors affecting solubility, causes of solubility, applications of solubility product concept and its limitations.

Table 4.4 indicates that teachers found the exemplary materials very useful and relevant for A-level students. Apart from helping in teaching the solubility (soluble and insoluble salts) of various salts, the materials were found to provide enough opportunity for students to carry out experiments themselves, make observations and discuss results. They stated that the micro-scale experimental approach provided a short and easy way of exploring solubility of some common salts in water. On content and structure of the materials, all three teachers expressed satisfaction of content coverage and good presentation of the subject matter as illustrated in the following responses: *"the structure is simple and the presentation of the subject matter is very clear. Experiments are clearly explained, uses few and simple apparatus, they are easy to handle and allow use of small amount chemicals to conduct many experiments within a short time. Even inexperienced teachers can use the materials without difficulty.*

In their responses, teachers in both schools said that they liked most the micro-scale experiments on exploring solubility of various salts in water because they were simple to handle, exciting and helped students to investigate solubility of many salts in a very short time. One teacher specifically said he liked the use of plastic sheet and plastic pipettes as they allow use of small amount of chemicals but also many experiments can be done within a very short time and hence they are economical. Teachers also mentioned the pre-lab exercises as an aspect they liked because they helped students to familiarize with basic pre-requisite knowledge and they make students aware of what they are going to do during the practical. In addition, the teacher stated that the use of simple experiments in the first lesson was very motivating for students and stimulated their interest in subsequent lessons.

Two teachers also indicated some aspects which they did not like about the lessons. One teacher stated that he did not like the experiment involving dissolution and diffusion of potassium permanganate because its set-up involved a lot time and needed extra care from both teachers and students to make proper observations. Another teacher indicated that he did not like the time estimated for introducing the lesson. Time was not enough for some lessons; it was difficult to make the necessary review of important concepts of solubility. All teachers felt that shorter time would be spent on doing experiments if students were given the worksheets to read one or two days in advance.

Responding to what aspects they would like to take out or add to the materials, all teachers indicated that all components were relevant and appropriate to the syllabus used. However, they suggested for addition of 'Common-Ion Effect' and the possibility to include salts (cations and anions) specified for the A-level qualitative analysis practical as well as an accompanying table of expected experimental results.

On anticipated problems, if they were to do micro-scale experiments in an ordinary classroom, teachers felt that there could be no problem provided adequate preparation is made (e.g. more sets of reagents with less number of students per group) and clear information safety precautions from toxic chemicals, such as heavy metal ions, is provided.

4.7.2 Student experiences with micro-scale chemistry practical activities

Student views and experiences with practical lessons conducted by way of micro-scale were obtained through questionnaire and interview. The results are presented under the following themes: aspects of the lessons students liked most and those they liked least, and the differences between the try-out lessons and regular chemistry lessons.

Aspects of the lessons students liked most (least)

The results from both questionnaire and interviews indicated that students' opinions and experiences with the micro-scale chemistry approach were very positive. The majority of students liked the experiments and the way they made use of plastic sheets and grid paper in place of test tubes and beakers. They indicated that they were fascinated by the formation of the precipitates and the different colour changes. They commended on how simple the set-up of the experiments was and how little time they needed to carry them out. The following comments illustrate students' reactions to the micro-scale approach to practical work.

- *'We used one sheet for all experiments instead of several test tubes and we were able to observe and compare many changes (reactions) at the same time. Experiments do not consume a lot of time'.*
- *'Reactions were fascinating' and 'We were able to see physically the different reactions'.*
- *'It was surprising to see two white crystals combining in a water drop to form one thing of different colour, which was a nice yellow'.*
- *'Enjoyed doing practical by ourselves'.*
- *'Experiments done on micro-scale were simple, used small amounts of chemicals and did not involve frequent washing rather than those done on test tubes in our regular classes'.*

Students also indicated how they had enjoyed doing the experiments by themselves, showing their increased positive attitudes towards chemistry:

- *'We felt like great chemists in the world'.*
- *'I thought I will never master chemistry, now I can'.*
- *'Learned that chemistry is an interesting subject'.*
- *'Experiments helps to be aware and love chemistry'.*

Students from school 1 indicated that normally they do not do any practical work in chemistry. This try-out had been the first time they were doing practical work on their own since they started Form 5. The students pointed out that apart from the type of practical (with plastic sheets and drops of reagents) the class was also different because of the good participation of the teacher and the good learning environment that was created during the sessions: *'Yes, we are very happy; teachers are more charming than in normal classes. It was a very conducive environment for us to learn'*.

Aspects of micro-scale chemistry lessons students didn't like

Few students from both schools listed some aspects of micro-scale lessons which they did not like. Five students (13.5%) from school 1 indicated that they did not like the experiment on the diffusion and dissolution of potassium permanganate because it was difficult for them to observe and time consuming. Four students (10.8%) from the same school stated that they did not like experiments demonstrated by the teachers to the big group because it was very difficult to observe the changes and some students did not pay attention to it. Very few students (about 5%) indicated that they did not like washing the droppers after each experiment because it wasted time. Similarly, few students (13.5%) from school 2 felt that the boxes (squares in the reaction grid) were small and it could cause contamination of reagents between the different squares. Students also indicated not to prefer sharing reagents among many groups because it could be a source of errors in their experiments.

Differences between micro-scale chemistry and regular chemistry lessons

Many students (57%) from school 1 indicated that in the micro-scale chemistry based lessons they were more actively involved in the learning activities compared by theoretically oriented lessons in normal chemistry classes. They specifically stated that in their normal class most of the times they were used to sitting alone but in these lessons all were actively participating in practical activities '*We worked like bees*'. Moreover students indicated that the lessons in the tryout involved them doing, observing and seeing results immediately, discussing and coming up with conclusions. Almost all students (95%) who completed the questionnaire from school 2 indicated that doing experiments on micro-scale as the main difference between tryout lessons and regular classes. They described the approach as simple, accurate and fast as it took them only short time to complete several experiments within one practical session. Likewise, students indicated that in the tryout there was good participation of teachers compared to regular classes. While only one (5%) student said experiments in the tryout were difficult to explain, some students (45%) from school 2 did not respond to this item.

During the interview students described the good interaction between teachers and students, and between students and students, good cooperation between teachers and teachers during the lessons created a very good learning atmosphere for them. They felt this as the major difference between the tryout lessons and their regular chemistry classes, where they are not used to interact with the teacher in a friendly manner like they did in the tryout. They said they felt free to ask teachers questions and teachers were ready to answer them. Expressing their feelings about practical work in terms of who actually does the experiments' students said that they prefer to do experiments themselves but under the guidance of the teacher. They felt that it is better for them when the teacher makes clear what they are supposed to do rather than trying to do things they completely do not know.

When asked, if they could have more of anything in their chemistry classes, what would that be, students answered: '*get plastic sheets, get reagents and do more experiments for even other topics; chemistry books, especially in inorganic chemistry; more exercises and practices on solubility and Ksp calculations*'. Similarly, when asked what they would like less in their chemistry classes they answered: '*lecture hours should be reduced. Too much lecturing makes the lesson boring*'.

From the students reactions it became clear that students liked the approach and they found it easy to use in carrying out the experiments themselves. On the hand, students' reactions showed that the teacher is important in guiding their learning. They indicated that without the teacher making clear the purpose of practical activities it would be difficult for them to learn from the activities.

4.7.3 General observations from the classroom

During the classroom try-out the researcher participated both as observer and facilitator. The general observations as noted by the researcher during classroom try-out are summarized under lesson preparation, lesson execution, and conclusion of the lesson.

Lesson preparation

Teachers prepared the larger part of the practical class during the interactive preparation sessions with the researcher. Teachers at each school used the teacher support materials to prepare the experiments for the class without many difficulties. They were able to try-out most of the experiments in advance as suggested in the materials. Only in a few cases, where they noted some errors in reagent specifications could not get the desired results and discussed it with the researcher to make the necessary amendments. For example, teachers from school 1 made adjustments on the concentration of Barium nitrate solution and on the experimental set-up involving dissolution and diffusion of potassium permanganate. Teachers were observed to be excited from their own experimental results and eager to see what will happen when they implement them with students in the class.

Lesson execution

During the lesson execution, teachers of both schools were well prepared for the start of the lessons. They started the class by organizing students in small groups according to suggested format (2-3 students per group) in the curriculum materials. There were only few (2-3) groups, which comprised up to 4 students. When all groups were formed teachers introduced students to the activities they were going to do in the practical starting with the pre-lab exercises, which lasted for about ten minutes. However, teachers did not ask students to present and discuss answers for the exercise; instead each group submitted written answers for marking.

Following pre-lab exercise teachers asked students to read the worksheets carefully before starting any experiment. Students were attentive and appeared excited for the lessons. As students were carrying out experiments in small groups teachers walked around the groups and provided support where students had difficulties. Many students had problems of identifying colours of precipitates as well as solutions. Many students asked their teachers and peers why some reactions products kept changing colours as they stayed longer. Teachers gave feedback to individual groups as they asked for help. All teachers appeared to have inadequate skills of stimulating students to talk about their observations during the demonstration experiments. Teachers had also difficulties in managing the time spent for small group discussions. Discussions continued beyond the estimated time and as a result there was very little time left for giving feedback to the whole class and making conclusions. Conclusions were made in the last session by a general discussion and reflections on all the experiments and the teacher gave feedback on areas which many students had difficulties.

Like their teachers, students' motivation and involvement in the practical activities in both schools was very good. Students appeared calm most of the time concentrating on the experiments in small groups. Everyone wanted to practice doing the experiments, and some students repeated experiments many times. There were also few groups who managed to finish performing the experiments before estimated time (30 minutes) for the students' practical. For teacher demonstration, students seemed not to pay much attention to the demonstration. They kept reading their worksheets. They appeared to have difficulties watching the experiments and listening to the teachers' explanation because only one table was used for demonstration.

4.7.4 Science student teachers' experiences with and opinions about the msce approach

The results from the try-out with science education students at the university indicated that the content and the practical activities of the exemplary materials are relevant for the A-level chemistry curriculum. They felt that the exemplary lessons provided a good link to qualitative analysis, which is one of the major topics in chemistry practical work offered to A-level students in Tanzania secondary education. They specifically gave an example of the lesson on identification of ionic composition of unknown salts as part of the topics in A-level qualitative analysis practical. Also students indicated that the exemplary materials provided good examples of activities that can be used to engage students in critical thinking. Some of the statements that illustrate these responses are *"the activities involved much use of the brain", it involved us to think critically and analyze the observation we made. The practical activities are exciting, challenging and interesting"*.
In terms of active participation and group cooperation, students indicated that, the approach was very good because it created good cooperation among students within the group and between small groups. They felt that they were all actively involved in the experiments and in small group discussions *"Every student is actively participating in different or various activities. It stimulates interest in chemistry"*. Almost all students indicated that they enjoyed doing experiments on micro-scale as they used few and simple apparatus, and with just a small amount of chemicals they were able to produce the same results as those obtained when they use larger amounts of materials.

On the practicality of the MSCE approach students said that the topics/ lessons in the materials were arranged in a good and logical order, which enabled them to follow and perform the experiments easily with minimum help from the facilitator (course lecturer/ researcher). They stated that they were able to get the results of the experiments immediately. Apart from being able to carry out the experiments without problems and within a short time they said that displaying results on one plastic sheet enabled them to compare observations for various reactions easily.

However, science education students pointed out that the micro-scale chemistry was not a favourable method for reactions that generate poisonous gases and require concentrated acids. Also they pointed out that the method was confined to solubility only. Moreover, students suggested provision of information and apparatus on how to protect from toxic chemicals such as silver, lead and barium solutions.

Revision of the second prototype

Based on the results of classroom try-out and appraisal of the materials, the second version of the prototype was revised. The revision involved lesson duration, preparation of expected experimental results, development of an additional lesson, and revision of some experiments and organization as outlined below:

- *Lesson plan and timing*: Lesson plan and timing of all the four lessons were revised to fit four 40-minute periods (1 practical session, which is followed by most schools). The activities in each lesson were developed in such as way that it would be possible to teach half the content by using 2 periods (80 minutes) in one session and continue with the remaining content for another 2 periods. This was done to accommodate both, schools which use one double period (80 minutes) for practical work and those which use two double periods (160 minutes). Also a detailed plan indicating students' and teachers' activities were included in the teacher materials.
- *Expected experimental results*: All the experiments were tried out beforehand and the results incorporated in the teacher materials.
- *Teaching strategies*: suggestions for tips, questions and possible answers to assist teachers how to stimulate group and class discussions have been included in the exemplary lesson materials.
- *Additional lesson on the common-ion effect*: A new lesson was developed to cover the concept of common ion effect and how it is related with solubility of a sparingly soluble salt. However, this lesson was shorter than the other two lessons, because there were not many concepts compared with the other four lessons. The content of this lesson was developed to be taught for only 80 minutes.
- *Sharing of chemicals*: To reduce sharing of chemical by whole class a framework for group work was suggested and droppers for each solution were prepared.
- Experiment on KMnO4 was taken out of the materials, because it was not achieving the idea of MSCE. Instead another shorter experiment was introduced in lesson 1. All demonstration experiments were revised and meant for student own experimentation.

Following the revision third prototype was produced and appraised by a panel of science education experts. The expert interactive panel session and the results of the appraisal are described in the next session.

4.8 INTERACTIVE PANEL SESSION WITH EXPERTS

The last cycle of formative evaluation involved a "walk through" and appraisal on the third prototype. On the basis of the results of the tryout and user appraisal the third prototype was produced consisting of five lessons. Table 4.5 provides an overview of the lessons.

The review of this prototype was done in preparation to field testing of the curriculum materials. It was formally organized during one of the researchers' study visits to The Netherlands. The main focus of the review was to gather information on the quality (validity) of the materials toward final improvement for use in the field test. Five international experts with varying expertise in chemistry and chemistry education appraised the third prototype in an interactive panel session held at the Vrije Universiteit Amsterdam. Two weeks before the appraisal session, every member of the panel received a copy of the materials for the topic of *solubility and precipitation* together with a brief description of the context of the study and some guiding questions for reflections. The guiding questions covered the various aspects of the exemplary materials including: lesson structure, learning objectives, sequencing and timing of learning activities, relevance and accuracy of content, suggested assignments for assessing student learning. At the start of the interactive session, the researcher made a short presentation outlining the purpose of the study and the context in which the materials were intended to be used. After the presentation, experts walked through each lesson and raised questions, which some of them were clarified by the researcher and others by members within the panel. During the session the researcher took notes on the comments. Based on the results of the interactive session with the expert panel revision on the prototype was made immediately and resulted into the fourth version and final prototype.

Table 4.5 *Summary of exemplary lessons in the third prototype for teacher support materials*

Lesson	Description of lesson
1	*Introduction to solubility and precipitation*: In this lesson, students explore and revise important concepts used in solution chemistry, such as solute, solvent, solution, dissolution, ions, precipitate. Students are introduced to micro-scale chemistry techniques through three short student experiments, followed by analysis and group discussion on the experiments' observations.
2	*Investigating solubility of some common salts in water*: students use micro-scale approach to perform several experiments involving reactions which occur in aqueous solution to generate a solubility table for some common salts in water.
3	*Identification of unknown solution applying solubility rules*: Students are confronted with a problem of misplaced labels of six chemical solutions and perform experiments on micro-scale to identify the correct label of each solution using observed properties and solubility rules established in lesson 2.
4	*Solubility product constant*: Students are introduced to quantitative aspects of solubility product constant as a description of saturation. They are also exposed to various calculations involving solubility and solubility product constant.
5	*Solubility of a salt and Common Ion Effect*: In this lesson students explore how the presence of a common ion in a solution affects the solubility of a sparingly soluble salt. This is done through short student experiments and discussion whereby students attempt to dissolve one salt in different solvents, some containing an ion common to both, the solute and solvent.

Results of the interactive panel session

The results from the expert panel session were based on the walk through comments that were made on the third version of the lesson materials. All the five experts expressed that the overall layout of the materials looked very good. In general the experts commented very positively on the micro-scale chemistry experiments that were designed for students' practical work. Experts' offered specific comments on aspects of the materials which needed attention for improvement. These aspects focused mainly on adequacy of content, correct use of chemistry language, suggested teaching pattern, and class exercises and homework for students. Experts' comments and suggestions are summarized in Table 4.6.

Table 4.6 *Expert panel comments on the third prototype*

Comment/observation	Suggestion
Content	
▪ The concepts of *solubility product* and *ionic product* have not been explicitly differentiated. They need to be thoroughly explained to teachers ▪ It is not a good idea to introduce the units of solubility and concentration in the introductory lesson. It might be too difficulty for students to follow in the first lesson. ▪ The questions for pre-lab exercise in lesson 2 can be more meaningful if asked after students have done the practical.	▪ Discuss the meaning and differences between the two concepts with teachers or include a concise description and examples in the teaching notes. ▪ Introduce solubility units when dealing with calculations of solubility and solubility product ▪ Change pre-lab questions to post-lab exercises
Teaching methodology	
▪ Reactions of experiments 1-3 from lesson 1 depends largely on conditions under which the experiment is carried out. These are not adequately explained in the lesson. ▪ In some lessons, introduction has been used and in others start of the lesson has been used. Consistence is lacking	▪ Include the explanations that are necessary for the reactions to (or not to) occur in each experiment in the teacher notes. ▪ Use same subtitles in appropriate sections for every lesson.
Suggested student assignment (homework)	
▪ Class exercises and homework questions on solubility units in lesson 1 do not reflect on the experiments done. ▪ Lesson 4 could provide more opportunity to stimulate student thinking through more challenging questions involving calculations on Ksp and Q.	▪ Question for exercises and homework for students should focus on the experiments done to link ideas and observations made. For example in lesson one, students could be asked "what can you say about the solubility of lead iodide in water at 25^{o}C compared with that of lead nitrate and potassium iodide? ▪ Include more examples and challenging questions in students' homework.

Experts' comments as presented in Table 4.6 focused mainly on lessons 1 and 4. There were no major comments for improvements on the other three lessons, except on pre-laboratory exercises for lesson 2. Apart from commenting on specific lessons, experts suggested that since micro-scale chemistry was a new approach to the teachers, a short description about the approach was important to be included in the overall introduction of the prototype.

4.9 CONCLUSIONS AND IMPLICATIONS FOR FURTHER DEVELOPMENT

This chapter has dealt with the design and formative evaluation of prototypes for the topic of solubility and precipitation to support teachers with the implementation of micro-scale chemistry experimentation (MSCE) in Tanzania A-level classes. The focus of evaluation activities was on exploring the validity and practicality of the exemplary materials and the MSCE approach. The evaluation activities were conducted through expert appraisals (both at individual and panel levels), classroom try-out and user appraisal.

The results from both individual and expert panel appraisals indicate that experts found the overall layout of lesson materials good with most of the experiments presented clearly in both teacher support materials and student worksheets. Experts' comments indicated that the materials were relevant and appropriate for the grade level they were designed. They also felt that the information for the teacher on how to check learning effects was adequately given in the materials. Apart from their positive comments, experts observed some important components of the materials that needed improvement to enhance the quality of the prototypes:

- There was an underestimation in timing of learning activities, such as lesson introduction and small group presentations for some lessons (e.g. lesson 1).
- Procedural specifications on how the lessons will be executed in class and what roles do teachers and students play during the lesson was not adequately outlined in the teacher support materials;
- An opportunity to explore students' understanding of key chemical concepts (such as ions, cations, anions, soluble, insoluble, diffusion) in the different lessons needed to be provided at the beginning of the lesson or explained thoroughly at the end of each lesson.
- Lesson summary and pre-laboratory exercises in some of the student worksheets provided answers to the students' questions beforehand. Experts felt that these were pre-empting student thinking about the experiments and exercises they were going to do.
- To increase learners' involvement and participation all teacher demonstration experiments were suggested to be re-designed for students own experiments because it would be difficult for students to watch a demonstration done on micro-scale.

The results from the classroom try-outs showed that the teacher support materials and the student worksheets designed for micro-scale chemistry practical work demonstrated some potential of its validity and practicality in the circumstances they will be used. Teachers found that the materials provided adequate support information during the preparation of students' practical work with the new approach. Teachers from both schools demonstrated that they were able to use the materials to prepare and successfully try-out the experiments before bringing to the class. An observation on initial successive experience of teachers to use the micro-scale approach during the preparation session is that teachers got excited and increased confidence to tryout the materials in their class with students.

Teachers' general impressions on the materials as used in the class indicate that teachers found the materials and the MSCE approach very useful. They stated that the materials presented the approach in a simple but effective manner. The materials cover most of the content as specified in the chemistry syllabus, and provide ample opportunity for students to be actively involved in practical work. Moreover, teachers indicated that the new approach needed less time, not sophisticated equipment and can be carried out during theory lessons and in ordinary classrooms (not necessarily in laboratories). Teachers indicated that the approach could also be useful in lower forms at O-level. On the other hand, teachers observed some deficiencies and suggested for amendment mainly in the area of the contents of the lessons compared to the syllabus outline and the timing of some of the components of the lessons.

Initial students' experiences indicated that they were excited by their involvement in the micro-scale chemistry lessons. Majority of students stated that they enjoyed doing the practical (mixing drops and observing colour changes) by themselves and the cooperation from the classmates and the teacher. They indicated that their teachers had been much friendly during the lessons. They also commented on how little time the experiments had taken. Furthermore, student responses suggested that they had changed their attitudes towards the subject in a positive way. Some indicated that they started to like and to understand chemistry.

These results suggest that the MSCE curriculum materials to a great extent are *valid* and *practical* for use with A-level students in class (keeping in mind the suggestions made by experts and teachers for adjustments in the materials). Moreover, the materials have also shown that they can be *effective* in providing positive learning experiences for students whereby they enjoy what they do (e.g. carry out experiments for themselves, collaborating with peers and actually liking and understanding what they do). The next chapter (chapter 5) discusses in detail the effectiveness of the MSCE approach.

CHAPTER 5
Field test

This chapter presents the design and results of the field test carried out to investigate the impact of a micro-scale chemistry experimentation approach on the teaching and learning of A-level chemistry in Tanzania. Section 5.1 describes the aim, research questions, and the research approach used during the field test of the MSCE curriculum materials. The sample and methods for data collection used to address the research questions are presented in section 5.2 and 5.3. Section 5.4 presents the results of the field test, including observed classroom practices, teachers' experiences with student learning using the MSCE approach, and students' experiences with and learning outcomes from the MSCE activities. In section 5.5 conclusions are drawn about the teaching and learning of solubility and precipitation with micro-scale chemistry experimentation.

5.1 DESIGN OF THE FIELD TEST

Exemplary curriculum materials (teacher support materials with student worksheets) designed and developed for the sub-topic of solubility and precipitation were used to introduce the MSCE approach in the teaching and learning of A-level secondary school chemistry in Tanzania. The materials (in the form of lesson units) were developed through a prototyping approach and involved four versions. The first three versions were used to explore the validity and practicality of the MSCE approach during the study's design and formative evaluation stage (see chapter 4). The final version (fourth prototype) of the materials was used during the field test (see Appendices D1, D2 and D3 for examples of the final version of the exemplary curriculum materials).

5.1.1 Aim and research questions

Field testing of the final version of exemplary curriculum materials aimed to evaluate the impact of micro-scale experiments on teaching chemistry in Form 5 classes. The main research question for this study was as follows:

What is the impact of the MSCE approach on teaching and learning chemistry in Tanzanian A-level classes?

Based on this question, three sub-questions were formulated to guide the investigation:

1. How is the MSCE approach actually implemented in the classroom?
2. What are the teachers' opinions of MSCE based lessons?
3. What do students experience and learn from the MSCE approach?

Students' experiences with micro-scale experiments in solubility and precipitation lessons and their learning results from these lessons were considered to be the main impact indicators of the MSCE approach. Thus, data on actual classroom practices using the MSCE approach (sub-question 1) and on teachers' opinions about the approach (sub-question 2) served primarily as input to interpret information on student learning (sub-question 3).

5.1.2 Research approach

To evaluate the impact of the MSCE approach as implemented in the school classroom environment, a quasi-experimental research design approach was applied. A pretest-posttest non-equivalent control group design (NCGD) (Creswell, 2002; Krathwohl, 1998; Mertens, 1998) was used to compare the impact of the MSCE approach versus the normal 'traditional' teaching approaches in the teaching and learning of solubility and precipitation in A-level chemistry classes.

Cresswell (2002) describes the pretest-posttest non-equivalent control group design of the quasi-experimental approach as the design where the researcher assigns intact groups to the experimental and control conditions, administers a pre-test to both groups, conducts experimental treatment activities with the experimental group only, and then administers a post-test to assess the difference between the two groups. One of the advantages of this design is the opportunity to use existing groups (classes) in given educational settings (Creswell, 2002). The quasi-experimental research approach was chosen as a suitable and feasible design for this part of the study because it was not possible to randomly assign the students to different conditions in the study's context. The study involved groups of students organized in classes according to subject combinations, and random assignment would disrupt the learning process in the schools. The use of existing classes was also important because the study's aim was to compare the impact of the MSCE approach with other teaching approaches to maximise ecological validity of the results.

In addition to ecological validity, it has been argued that the pretest-posttest non-equivalent control group quasi-experimental design provides control for confounding variables by tracking a comparison group that is as similar to the experimental group as possible (Krathwohl, 1998). In this design, the pre-test measurement helps the researcher to establish if groups are similar or different at the beginning of the study. The pretest-posttest non-equivalent control group has potential protection against threats to validity related to 'history', 'maturation', 'testing', 'instrumentation', 'selection' and 'mortality' (Krathwohl, 1998). However, unlike the true experimental design where the researcher has full control throughout randomization, this design does not allow for either full control over scheduling of experimental conditions or the random assignment of participants to equivalent groups (Creswell, 2002).

5.2 SAMPLE

5.2.1 The schools

The participants for the study came from four secondary schools selected from two regions, Dar es Salaam (DSM) and Iringa. Two schools were involved in each region: one school was designated for the experimental (treatment) group students and the other was designated for the control group. The schools from these regions were selected based on purposive sampling (Cohen, Manion & Morrison, 2000; Krathwohl, 1998). Selected schools were those in proximity to the researcher who could then make frequent visits and follow-ups, which was necessary for the study. Besides proximity, the four schools were also selected because of (a) willingness of chemistry teachers to participate in the study, and cooperation and commitment by school administration to accommodate the study (established during the researchers' pre-field visits); (b) availability of a reasonable number of Form 5 students in the Physics, Chemistry, and Biology 'PCB' stream (at least two classes or one class of 50 students); (c) match of teachers' schemes of work to the topic of investigation (that is, solubility and precipitation taught to Form 5 students during the same academic term across schools); and (d) reliable means of transport to the regions and schools.

All participating schools were large (1000–1600 students) Tanzanian government secondary schools with A-level science streams. Table 5.1 provides a summary of background information on the schools, teachers, and students. In the table, schools ES1 and ES2 represent the experimental group and schools CS1 and CS2 represent the control group. Similarly, teachers TE1 and TE2 belong to experimental schools; and teachers TC1 and TC2 belong to the control schools.

5.2.2 The teachers

Initially the plan was to involve two teachers from each of the four schools, one teacher per class. However, due to school timetable arrangements where two or more classes are combined and taught by one teacher, only one teacher was involved per school. In all participating schools, teachers were those currently teaching the classes (streams) involved in the study, except at school ES1 where the teacher in charge of practical work was also partly involved in providing additional support for class supervision and logistics during laboratory sessions. All the four participating teachers were male with varying backgrounds. Two teachers, TE2 and TC2 had bachelor degrees with education and teaching diplomas. The other two teachers, TE1 and TC1, had bachelor degrees in Agricultural science. None of the teachers had been exposed to any kind of formal in-service teacher education since graduation. Table 5.1 provides background information for each participating teacher.

Table 5.1 *Summary of background information on the schools, teachers and students in the study*

Schools	**ES1**	**ES2**	**CS1**	**CS2**
Region	Iringa	DSM	Iringa	DSM
School type	Boys & Girls	Boys & Girls	Boys only	Boys only
Level	A-level only	A/O-level	A/O-level	A/O-level
Number of Form 5 chemistry classes	15	4	6	4
Average class size	25 - 30	25	25 - 35	25 – 30
Teaching staff (chemistry)	6	3	2	5
Teachers involved	1	1	1	1
Teachers	**TE1**	**TE2**	**TC1**	**TC2**
Gender	Male	Male	Male	Male
Teacher background	B.Sc. (FST)	B. Sc.(Ed.) Diploma(Ed)	B.Sc. Agric.	B. Sc. Ed Diploma(Ed)
Teaching experience at A-level	1.5	2	1.5	1
Teaching experience at O-level	–	4	–	20
Other	–	HOD	–	–
	No INSET	No INSET	No INSET	No INSET
Students				
Grade Level (Form)	Form 5 PCB	Form 5 PCB	Form 5 PCB	Form 5 PCB
Number of students involved	50	38	63	44

Note: B.Sc. (FST): Bachelor of Science (Food, Science and Technology); B.Sc. (Ed.): Bachelor of Science with Education, B.Sc. Agric.: Bachelor of Science in Agriculture; HOD: Head of Department.

5.2.3 The students

Table 5.1 shows the student number and distribution throughout the schools. The MSCE exemplary curriculum materials were based on the Tanzanian Chemistry syllabus for A-level students. The students involved in the study were determined by the nature of their subject combination and the number of participating classes (2 classes per school, average class size 25) and teachers' class allocation. A total of 195 Form 5 science students enrolled in the 'PCB' stream from the four schools (ES1, ES2, and CS1 & CS2) participating in the study. Out of the 195 students, 107 came from the control schools and were all boys. The experimental school offered 88 students (38 boys, 50 girls).

All participating students had finished their O-level chemistry and were selected to join the A-level program (PCB stream) from a variety of schools. This particular group of students was conveniently selected for the study's focus as they comprised participants studying all three sciences as their major or principal subjects. Thus they were considered to be appropriate sources of feedback on the impact of the MSCE approach on teaching and learning secondary chemistry.

It can be noted that the sample had an unequal distribution of boys and girls between the experimental and control group classes. There were fewer girls than boys and all were in the experimental group. However, this unequal gender distribution favoured the control group in view of other findings (Urassa & Osaki, 2002) which showed that secondary school girls in Tanzania normally perform more poorly in science subjects than boys.

5.3 METHODS

The study employed four types of data collection methods: classroom observations, interviews with teachers and students, student knowledge tests, and student questionnaires. While all methods were used to gather data from the experimental schools, classroom observation and student tests were also used to collect data from the control schools (see Table 5.2). Triangulation of methods was used to enhance the corroboration of findings (Cohen, et al., 2000; Miles & Huberman, 1994). Table 5.2 presents an overview of data collection methods and related research themes.

Table 5.2 *Data collection methods*

	Data collection method						
	Experimental group					*Control group*	
Research theme	*CO*	*IT*	*ST*	*SQ*	*IS*	*CO*	*ST*
1. Classroom implementation	√					√	
2. Teachers' opinions		√					
3. Student learning			√	√	√		√

Note: CO: Classroom Observation; IT: Interview with Teachers; ST: Student pre- and post-tests; SQ: Student Questionnaire; IS: Interview with Students.

5.3.1 Instruments

Five instruments were used to collect data for this study: a classroom observation checklist (curriculum profile); a teacher reflective interview scheme; student pre- and post-tests on understanding solubility and precipitation concepts; a student questionnaire; and a student interview scheme. The instruments are presented in the next sections.

Classroom observation

The classroom observations in the experimental classes were conducted with the help of a curriculum profile. Van den Akker and Voogt (1994) define a curriculum profile as a set of statements about teacher and student activities during the observed lessons. In this study, the curriculum profile was developed and used to gather data on classroom practices by both teachers and students during the implementation of MSCE-based lessons. The profile focuses mainly on the features of MSCE exemplary curriculum materials: pre-lab exercises, small group practical activities, discussion and reflection on the activities, and consolidation of student learning outcomes. Some of the statements in this instrument were adapted from curriculum profiles that were developed and used in similar research studies (Ottevanger, 2001; Tilya 2003).

The curriculum profile (see Appendix B1) was comprised of action statements organized under three sections: introduction to the lesson, body of the lesson, and the conclusion. Each section consisted of statements indicating specific teacher and/or student activities during the lesson. Each profile statement could be scored with a plus (+) to indicate that the activity was observed, a minus (-) to indicate the activity was not observed, or a plus/minus (±) to indicate that the activity was partially executed. The following examples illustrate activities or classroom observations, which could be scored with a plus (+), a plus/minus (±), or a minus (-) for each lesson stage.

- *Introduction*: Teacher clearly explains the purpose of the practical to determine the identity of six unknown chemical solutions based on observed properties and established solubility rules (+). The teacher explains the purpose of the practical, but not very clearly to identify ionic composition of six unknown salts without specifying the criteria (±). Teacher does not relate pre-laboratory exercises to student practical to test the solubility of a sample of salts that students have predicted in a chart (-).
- *Body of the lesson*: Students are able to work with apparatus and materials with little assistance from the teacher (+). Students are able to work with apparatus and equipment with lots of support from the teacher (±). Students have difficulties in using micro-scale apparatus, for example, placing drops on the plastic sheets (-).
- *Lesson conclusion*: Teacher and students draw conclusions from the activity/experimental results and clearly link them to the lesson objective(s) (+). Teacher and students draw conclusions from activity without clearly reflecting on the objective of the activity/lesson (±). Teacher does not make any conclusions about the experiment’s findings (-).

Classroom observations in the experimental classes were conducted by the researcher and a research assistant. To prepare for classroom observations, the researcher and research assistant both participated in a one-day interactive preparation workshop at one of the experimental schools (described further in section 5.3.2). After the workshop, the observers walked through the curriculum profile instrument, and discussed and agreed on how to use the instrument during lesson observation. Each observer was required to make brief notes on important observations that could not be captured by the instrument.

Three lessons (out of five) were observed at each experimental school. These three lessons constituted the major component of student practical work applying micro-scale chemistry techniques (i.e., lessons were selected on the basis of the main focus of the intervention). All lessons in school ES1 were observed by the researcher. The research assistant who participated in the preparation workshop could not participate during classroom implementation of the MSCE approach due to logistical problems. Two lessons in the second experimental school (ES2) were observed by the research assistant and one lesson was jointly observed by the researcher and research assistant. During the joint observation each observer completed the profile individually. After the lesson, the two observers compared their completed profiles to get an idea of the extent to which the scores from the two profiles were in agreement for each lesson phase (introduction, body, and conclusion). There was significant agreement on scoring of all sections except on two items in the lesson body concerning students recording observations correctly and asking questions about difficult parts of the experiment. The scoring of these items was considerably different between the two observers, and so they were left out of the analysis.

The classroom observations in the control classes were conducted to gain insight into the classroom implementation of solubility and precipitation lessons using the regular 'traditional' teaching methods. The observations focused on good teaching practices expected of a science lesson (Ottevanger, 2001). The observations were guided by the curriculum profile by considering only items applicable to the lessons (see items with (*) in Appendix B1). Along with the profile, notes were taken during the lessons to provide a descriptive summary of the classroom activities.

Three lessons were observed in the control classes, two lessons at school CS1, and one lesson at school CS2. The observed lessons at each school were among the first three double periods during the teaching of solubility and precipitation. All observations from the control classes were made by the researcher.

Teacher reflective interview

The interview with teachers was conducted to collect data on their experiences with and opinions of the MSCE approach, reflecting their views from the preparation phase to the actual use of micro-scale experiments in class. The two participant teachers of the experimental classes were interviewed individually. The interview scheme was partially structured and focused on teachers' general impressions of the MSCE lessons (preparation and execution in class), their opinions about conducting practical work using the micro-scale chemistry experimentation approach, and their views on student learning with the new approach. Other areas of attention during the interview included teachers' perceptions of what they themselves had learned from the new approach, difficulties encountered during classroom implementation, and their opinions about teacher support materials. The interviews were audio taped and transcribed. The interview questions are shown in Appendix B2.

Understanding the solubility and precipitation test (uspt)

A 15-item knowledge test was developed by the researcher to measure the understanding of chemistry concepts and principles in solubility and precipitation by both experimental and control group students. The test items were constructed on the basis of the A- level Chemistry syllabus content, which is used for all schools in Tanzania. The content of the test items included basic concepts related to solubility of ionic compounds, dissolution and precipitation reactions, use of solubility rules and precipitation reactions in qualitative analysis, solubility product, and the common ion effect.

The test consisted of 13 multiple choice items and two short-answer items. It was assumed that short-answer items would help to differentiate between students scoring well by chance on multiple choice items from those performing well as result of true understanding of the subject matter. Each of the multiple choice items had four options: one correct answer and three plausible distracters. One point was given for each correct answer for a total of 13 points. Also, each part of the short answer items was given one point for a total of eight points. The test items and the scoring scheme for all items are presented in Appendices B3 and B4.

For the purpose of content validation and reduction of errors, the test was reviewed by two university lecturers with expertise in chemistry and chemistry education and one experienced A-level chemistry teacher. After incorporating the recommendations of the reviewers, the USPT was pilot-tested in one A-level secondary school with 53 students (38 from Form 5 and 15 from Form 6), majoring in physics, chemistry, and biology (PCB), similar to the study schools. Form 5 students had not studied the topic content covered in the test while Form 6 students had studied it. The inclusion of both grades was to get feedback on the suitability and practicality of test items from those students who had studied the topic and those who had not. Students completed the test in an 80-minute period. Immediately after the test, the researcher held a discussion (a think aloud session) with 12 students chosen randomly from the two classes. The focus of the discussion was on the test's timing, clarity, difficulty level of questions, and content.
Following students' feedback, the test was revised again. The major revision was on test duration as the time of 80 minutes to complete the test was considered rather short relative to the cognitive demands of some questions. The test duration was increased from 80 to 90 minutes to accommodate reading time and clarification of test items. Other revisions were mainly editorial, focusing on the language used in constructing the items. Technical terms that made the questions unclear to most students (e.g. spectator ions) were expressed in more familiar words (e.g., do not take part in a chemical reaction) to make the question clearer to the students. The revised (final) version of the test was used for both pre-test and post test measurements. A total of 195 students from both the experimental and control groups took the test. The reliability of the test was estimated based on the multiple choice item responses and turned out to be quite low (alpha = 0.51). The reliability of short answer items was 0.69.

Student questionnaire

The student questionnaire was designed to gather information on students' experiences with and opinions of learning chemistry with micro-scale chemistry

experimentation. The questionnaire items focused on student opinions about practical work carried out on a micro-scale and on the perceived usefulness of specific learning activities carried out during lesson implementation. The questionnaire consisted of 27 close-ended items and three open-ended items organized in three sections. In the first section, students were asked to respond to 15 statements by indicating how strongly they agreed with the statement. A scale of 1 to 5 was presented for each statement item (1 = strongly disagree, 5 = strongly agree) for the students to indicate their response to the statements in relation to learning chemistry, group interaction, active participation, enjoyment of chemistry, and laboratory learning skills. Similarly, students were asked to respond to 12 statements by indicating how helpful they found pre-laboratory work, practical activities, analysis of experimental results and discussion, and homework assignments in facilitating their learning of chemistry. A scale of 1 to 5 was given for each statement item (1= not helpful at all, 5= very helpful) for the students to indicate their response. The open-ended questions focused on what students liked and/or disliked about the lessons with the MSCE approach as well as whether they experienced any difference between MSCE-based lessons and the 'regular' chemistry lessons.
The questionnaire was developed by the researcher on the basis of trial results and adapted from the student attitude questionnaire format used in a similar Tanzanian study (Tilya, 2003). The instrument was administered at the end of the classroom implementation of the MSCE approach at each experimental school. A total of 83 students from the two experimental classes completed the questionnaire. The questionnaire items are presented in Appendix C1.

Student interviews

Interviews with students were held to elucidate responses obtained from the questionnaire and validate observations made during the classroom implementation of the MSCE lessons. The student interview and questionnaire complemented each other, with interviews providing more depth to information collected through the questionnaires and classroom observation (Krathwohl, 1998).

Focus group interviews with a total of 20 students were held after the last classroom observation in the experimental schools. At each school, interviewed students were selected by their teachers from different groups according to ability (good, average, and weak) and gender. A group of 12 students (6 boys and 6 girls) were interviewed at school ES1 and another group of 8 students (4 boys and 4 girls) were interviewed at school ES2. The interview guiding questions were semi-structured and the researcher had the opportunity to expand them to allow students more flexibility in expressing their feelings about the MSCE lesson activities. The interview conversations were audio taped and notes were taken at the same time. The recorded conversations were transcribed and summarized after the interview. The student interview questions are presented in Appendix C2.

5.3.2 Procedures

Prior to the beginning of the lessons on solubility and precipitation, students in both the experimental and control groups were administered the knowledge pre-test at each participating school. The test was supervised by the subject teachers and the researcher. A post-test was administered at the end of lesson implementation at each school.

One week before the beginning of the treatment, teachers of the experimental groups were introduced to the MSCE approach in a one day interactive preparatory workshop. The workshop took place at each experimental school involving the researcher, the research assistant, and the participant teachers (including the head of department). During the workshop, the researcher introduced teachers to the main aspects of the teacher support materials (with student worksheets) that were designed to facilitate classroom implementation of the MSCE approach. Following the introduction, teachers used the support materials to prepare and try out the micro-scale experiments. The researcher and the research assistant acted as facilitators. At the end of the workshop, the researcher and teachers discussed and reflected on the MSCE practical approach, focusing on the results of trial experiments, organization of practical lessons, potential difficulties that students could encounter when performing micro-scale experiments, and how they could be helped.

Teachers from the control groups were not introduced to the MSCE approach but were requested to participate in the study by teaching the same content topic based on the syllabus according to their lesson plans and the methods they normally use.

After the introductory workshop, teachers in the experimental group schools used the exemplary curriculum materials designed with micro-scale practical activities in teaching solubility and precipitation lessons as part of the normal curriculum of chemistry. Students in this group were mostly taught through practical sessions. The practical lessons were conducted once a week and covered between two to four periods of 40 minute each depending on the length of the experiments in the lesson. A total of five lessons involving 14 periods (560 minutes) were conducted at each experimental school and the instructional period lasted for about four weeks. In both schools practical activities took place in the chemistry laboratory.

Like the teachers in the experimental schools, control group teachers also taught the same content topic as part of the normal curriculum of chemistry using regular 'traditional' teaching approaches. The traditional approach mainly involved lecturing and question and answer methods (teacher led-questions) without practical work. In each school, students were taught two 80-minute periods per week. The total instructional time per topic lasted for about three weeks and covered ten periods (400 minutes). Lessons took place in a normal classroom for both schools.

5.3.3 Data analysis procedures

Student test data

The internal consistency of the test (Cronbach alpha reliability) was estimated for the multiple choice items and appeared to be quite low (Cronbach alpha = 0.51). Due to the low reliability of the test, students' results were analyzed at the level of individual items. The proportion of correct multiple choice responses from both groups of students were computed and compared between the pre-test and post-test measurement to determine learning with the Chi-square test (χ^2). Similarly, the mean scores for each of the short-answer items were calculated for each group and compared between pre-test and post-test measurements using the independent t-test.

Student questionnaire and interview

The data gathered on the questionnaire were first analyzed quantitatively by computing the means and standard deviation for each of the Likert-type items on classroom learning experiences with MSCE approach. An estimation of the internal consistency (Cronbach alpha) of the questionnaire based on the close-ended items was found to be 0.78. Data from the open-ended questionnaire' and the interview were analyzed qualitatively. Some themes were established to help organizing the data into more meaningful information. For some data, original quotes from the participants were also used to illustrate the findings.

Classroom observation

Data collected through the curriculum profile were complemented by notes taken by the researcher and research assistant during the lesson. Both data and notes from the profile were analyzed following the features of profile guidelines (see 5.3.1 and Appendix B1). To characterize lesson implementation, descriptive summaries were written for each of the three lesson phases: introduction, body and conclusion. The data analysis focused on both teacher and student ability in executing classroom activities according to advice provided in the curriculum materials for the experimental group. Analysis of observation data for the control group was based on the type of lesson introduction, teaching method(s) used, teacher and student roles during lesson execution, time management, ways of assessing student learning effects, and conclusion of lesson activities.

5.4 RESULTS

This section describes the results of the field test, which was carried out to evaluate the impact of the MSCE approach on teaching and learning chemistry in Tanzanian A-level classes. The focus of the evaluation was on how the MSCE approach was implemented in the classroom, what opinions teachers had about the approach, and what students experienced and learned from MSCE-based lessons. Data on these questions were collected through classroom observations, interviews with teachers and students, a student questionnaire, and a student knowledge test (USPT). The results of the evaluation are presented and organized according to classroom implementation, teachers' opinions of the MSCE approach, and student experiences with and learning outcomes of the MSCE approach. Sections 5.4.1 to 5.4.3 provide a detailed description of the results.

5.4.1 Classroom implementation of solubility and precipitation lessons

Classroom observations were conducted to record and assess teacher and student activities during the implementation of solubility and precipitation lessons in the experimental and control classes. For the experimental classes the observation of the lessons was guided by the curriculum profile (see section 5.3.1). For the control classes the observation of the lessons was guided by a relevant part of the curriculum profile (see also in section 5.3.1).

Implementation in experimental schools: overall pattern

To get an impression of classroom implementation of solubility and precipitation lessons using the MSCE approach, three (out of five) lessons were observed in each of the experimental classes. Table 5.3 presents an overview of the observation results of each lesson per school.

Overall, the results of the two classes appear to be very much alike. The results show that teachers and students were able to implement most of the lesson activities according to advice provided in the curriculum materials. Teachers of both schools were observed to be well prepared for the lessons. All materials and equipment required for the lesson activities were ready at the start of the lesson.

Table 5.3 *Classroom implementation-observation results for three lessons of the experimental classes per school*

Curriculum profile instrument items	**Schools and Lessons**					
	ES1			*ES2*		
Introduction to the lesson	*L1*	*L2*	*L3*	*L1*	*L2*	*L3*
1. Teacher relates lesson to previous learning/future activities (e.g. checking homework)	_	±	+	_	±	+
2. Teacher groups the students for pre-lab and experimental work	+	+	+	+	+	+
3. Teacher introduces the lesson by an activity (e.g. pre-lab exercise)	+	+	+	+	+	+
4. Teachers links pre-lab exercises to current lesson or student practical	±	±	+	–	–	±
5. Teacher explains clearly the purpose of student practical	+	+	±	+	+	+
6. Teacher explains how students will obtain materials/equipment and how they are to be organized	+	+	+	+	+	+
7. Teacher informs students to read carefully all safety instructions before engaging in any experiment	+	+	+	+	+	±
8. Teacher asks group members to assign and share roles during activities (e.g. chairperson, secretary)	+	+	+	+	+	+
Body of the lesson						
1. Teacher explains to students how to use materials and equipment	+	+	+	+	+	–
2. Teacher demonstrates the experiment(s) to students	–	–	–	–	–	–
3. Students actively participate in hands-on activities	+	+	+	+	+	+
4. Teacher moves around groups to ensure experimental set-up and safety	+	+	+	+	+	+
5. Students use information from the worksheet to carry out the activities	+	+	+	+	+	±
6. Students demonstrate ability in working with apparatus and materials	±	+	+	+	+	+
7. Students work cooperatively in small groups	+	+	+	+	+	+
8. Teacher circulates among student groups asking/answering questions	+	+	+	+	+	+
9. Students seek help from the teacher during activities	±	+	+	+	+	+
10. Students discuss their experimental work/activities in small groups	+	+	+	+	+	+
11. Students show interest in the experiments they are doing	+	+	+	+	+	+
12. Groups present observations to the whole class	±	–	–	±	–	–
13. Teacher and students discuss the activities as a whole class	±	–	–	–	±	–
14. Teacher gives a short presentation at different times during activities to help students grasp major concepts	_	±	±	±	±	+
15. Teacher effectively manages timing of different learning activities	+	–	±	±	–	–

Table 5.3 *Classroom implementation-observation results for three lessons of the experimental classes per school (Continued)*

	Schools and Lessons					
Curriculum profile instrument items	*ES1*			*ES2*		
Lesson conclusion						
1. Teacher, together with students, draws conclusions from the activity/experimental work	+	+	±	±	±	_
2. Teacher discusses procedures and results with the students	±	+	±	_	_	+
3. Teacher guides students to understand differences in their results	+	+	_	±	+	±
4. Teacher helps students to relate the activity with theory	+	+	+	−	−	±
5. Teacher summarizes the main concepts learned from the activities	+	+	+	+	+	+
6. Teacher checks student learning (e.g. by oral questions, class discussions, by assigning homework)	_	+	+	+	+	+

Note: () denotes the activity was observed; ± denotes the activity was partially observed' and (–) denotes the activity was not observed; L1 – L3: lessons observed per class per school.

Each teacher had already indicated the sitting plan on the laboratory benches for group activities as suggested in the materials. Small groups were formed during the first lesson and maintained for the other lessons. The results show that the goals of the lesson activities were made clear at the beginning of the lesson. Students had clear information on the materials and equipment for the activities as well as safety instructions.

In all three lessons, students from the two schools were observed to be actively engaged in the learning activities. They performed most of the activities in groups of four. The activities involved a considerable teacher-student interaction and high student-student interaction. The climate of the lessons appeared to encourage active participation of all students. Students were observed discussing their work in small groups, asking for help from the teacher, and occasionally asking for help from fellow classmates in other groups. Teachers appeared friendly, interacting with students from one group to another.

During the activities, time management for small group discussion was observed to be problematic. Students spent more time analyzing, discussing, and comparing results with other groups than what was suggested in the curriculum materials. Teachers appeared unaware if they were running out of time for other activities such as small group presentations and lesson conclusions. It seemed that teachers became part of the learning groups. Most of the time teachers were observed to be busy circulating around groups and interacting with students in small groups.

Supervision of practical activities was another problem, which was noted during lesson observations at school ES2. The teacher was observed to spend a lot of time in one group, leaving other groups unattended when they asked for help. As a result, some students were seen moving from their groups to follow the teacher to another group to ask questions or for clarification.

Observation of lesson introduction in experimental classrooms

Table 5.3 shows that most activities performed during the lesson introduction were executed in both schools and aligned closely to the format suggested in the curriculum materials. The trend shows that teachers in the two schools were able to organize the students for group activities; conduct pre-laboratory exercises; make clear to students the purposes of the practical (experiments), describe how the materials and equipment for the practical could be obtained and organized; and stress the safety precautions during execution of the experiments. On the other hand, the results in Table 5.3 show that linking the pre-laboratory exercises to the main lesson activities was not properly done in all three lessons observed. Teacher TE2, for example, did not implement this item in two lessons (L1 & L2) and executed it only partially in the third lesson (L3). During the introduction phase, checking for homework appeared to receive less emphasis. Teachers' attention seemed to be more on pre-lab exercise and practical work than on checking and giving feedback to homework questions. Out of the three lessons observed, homework questions were checked in one lesson only.

Observation of body of the lesson in experimental classrooms

The actual micro-scale chemistry experimentation took place during this stage of the lessons. The teachers' role during the activities was to provide guidance and support. Teachers in both schools were observed to be quite involved in talking to students in small groups (see Table 5.3). They moved around the groups monitoring how members were participating in the activities and checking if there were any safety problems. However, working with more than ten active groups appeared challenging to both teachers. Teachers were kept busy throughout the lesson execution moving from one group to another giving advice and/or answering group questions. This was especially observed during the recording, analysis, and interpretation of experimental results. Some students were observed hesitant to record the results at first and kept repeating some of the experiments several times trying to confirm their first results. Others asked for help from the teacher or fellow students from other groups. In addition to facilitating group activities, teachers were expected to monitor the progress and timing of activities at each lesson stage. Teachers in both schools appeared to have difficulties in interrupting student discussions in the groups during analysis and interpretation of experimental results.

Small group activities involving students' experiments, analysis, and discussion of results were well executed in all the three lessons. Students were observed to be quite interested in the micro-scale experiments, collaborated very well in small groups, and interacted well with their teacher. Although they were using the MSCE approach for the first time, the results show that students of both schools demonstrated the ability to work with micro-scale equipment and materials including using small volumes of chemicals. On the other hand, the results indicate that the small group presentation of their observations to the whole class were not very evident in the lessons observed for both schools. Similarly, the results show that teachers of the two classes did not demonstrate any experiments to the students during execution of the three lessons observed.

Observation on conclusion of the lesson in experimental classrooms

The lesson conclusion involved several activities, which included the following: an overview of the main concepts learned from the activities; reflections on the procedures; the most difficult aspects of the practical with feedback from the teacher; an explanation of any theories or chemical principles governing experimental results; and a homework assignment. The execution of these activities was observed to vary from lesson to lesson and between teachers of the two classes. The results in Table 5.3 reveal that both teachers did very well in summarizing the main concepts and in assigning homework. Teachers also did fairly well in getting students to draw conclusions from the lesson activities and helping students to understand differences in the results. Observations also show some differences between teachers of the two classes in terms of discussing experimental procedures and results with students, and in helping them relate the conclusions of the activities/experiments to theory. These activities were better performed in classes of TE1 than teacher TE2. While teacher TE1 appeared confident in explaining the theory governing the conclusions of the activities/ results, teacher TE2 was observed to be lacking confidence in explaining to students the chemistry involved in most of the experiments, such as double replacement reactions and qualitative analysis of metal ions by selective precipitation method.

Implementation of solubility and precipitation lessons in control schools: overall impression

Three lessons were observed by the researcher in the two control schools to gain insight into how teachers were implementing solubility and precipitation lessons in the classroom. Two lessons were observed from school CS1 and one lesson from school CS2. At each school the lessons took place in a normal classroom. The results of the observations are presented in the following sections under the subheadings introduction, body of the lesson (lesson development), and conclusion of lesson. Table 5.4 presents an overview of observation results for the control classes for only a part of the curriculum profile not specific to the intervention and which could provide useful information about classroom practices in a science lesson.

Table 5.4 *Classroom implementation- observation results for the control classes per teacher*

	Teachers and lessons		
	TC1		*TC2*
Curriculum profile instrument items*	L1	L2	L1
Introduction to the lesson			
Teacher relates lesson to previous learning/activities (e.g. checking homework)	–	–	+
Teacher organizes the students for group activities	–	–	–
Teacher introduces the lesson by an activity, e.g. pre-lab exercises	+	+	–
Body of the lesson			
Teacher demonstrates the experiment to students	–	–	–
Students actively participate in experiments/hands-on activities	–	–	–
Students work cooperatively in small groups	–	–	–
Teacher circulates around students/students' groups asking/answering questions	+	+	–
Students seek help from the teacher during activities	–	–	–
Students discuss activities (exercises) in small groups	–	–	–
Teacher makes short presentation at different times during activities to help students grasp major concepts	+	+	±
Students and the teacher discuss the lesson activities as a whole class	+	+	–
Teacher effectively manages timing of different learning activities	+	+	+
Conclusion of the lesson			
Teacher draws conclusions with students from the activity/experiment	–	–	–
Teacher helps students to relate the conclusions of activity to theory	+	±	±
Teacher summarizes the main concepts learned from the lesson activities	–	–	–
Teacher checks learning of students (e.g. by oral questions, class exercises, homework questions)	±	±	±

Note: () denotes the activity was observed; ± denotes the activity was partially observed and (–) denotes the activity was not observed; L1 – L2: lessons observed, * Only applicable items of the curriculum profile are reported.

Observation on lesson introduction in control classrooms

In all three observed lessons classroom communication "flowed" primarily from teacher to students. Teachers started the lessons by either directly defining the concepts to be learned or by asking students to explain or define them themselves.

Teacher TC2 started the lesson by explaining the concept of solubility equilibrium and writing notes on the board. Students were observed to be silent, listening, and copying notes from chalkboard. Notes given to students were abstract as the teacher used only general expressions involving letters such as A or B to write chemical equations rather than real chemical symbols. Despite the use of abstract expression, the teacher introduced students to the lesson by systematically developing the theme or lesson title from previous learning. There were no questions asked by the teacher or by the students during this phase. After five minutes the teacher moved on to the main part of the lesson.
Teacher TC1 spent more time (15 -25 minutes) on the introduction than teacher TC2. Unlike teacher TC2, teacher TC1 started the lesson by asking questions to explore student ideas about the lesson topic. Examples of introductory questions included: *What do you know about 'solubility', 'Le Chateliers' principle', and 'Common Ion Effect'*. More interactions between the teacher and students were observed in the class of teacher TC1 than in the class of teacher TC2. Teacher TC1 encouraged students to talk by employing the 'question and answer' teaching strategy. He asked them questions and allowed some time for students to think about the answers. When one student gave an answer to the question, the question was transferred to other students for an alternative answer. Student answers were summarized on the chalkboard and followed by a brief discussion by the whole class. At the end of the discussion the teacher gave feedback by writing the correct answer on the board or by stating it orally. The transition from teacher TC1's introduction to the body of the lesson, however, appeared to be missing as there was no clear end of the introduction and beginning of next lesson stage.

Observation on body of the lesson in control classrooms

The development of concepts involving solubility and precipitation was carried out during this stage of the lesson. Teachers' presentation of the subject matter followed a similar style to that used during the introduction phase. It mainly involved lecturing supported by short class exercises and whole class discussion. Teacher TC2, for example, seemed to be well-versed in the lecture method and presented the subject matter systematically, starting by defining a concept, giving one or two examples, and writing notes on the blackboard. Students, for the most part, listened passively and copied notes from the chalkboard. They were not asked questions during this stage of the lesson. The teachers' lesson pace was observed to be fast but well managed, spending about five to ten minutes explaining one concept. In about 50 minutes the teacher had finished the main activities of the lesson.

During the lesson presentation, teacher TC1 maintained the 'question and answer' presentation style that was used in the introduction phase. Students in teacher TC1's class were a little more actively involved in the lesson compared to TC2's students. Every 10 to 15 minutes students were given a short exercise. The teacher wrote a question on the chalkboard and students wrote answers individually in their exercises books. One or two students were asked to read answers to the rest of the class, which were then briefly discussed by the whole class. The lesson pace was good; the teacher was able to complete all the activities within the allotted period of time.

Observation on conclusion of the lesson in control classrooms

In both classes, teachers concluded the lessons by asking students to complete a short exercise. Teacher TC1 invited one student to answer the question on the blackboard and asked others to comment. After two or three comments, the teacher made his comments and asked if there were any questions. There was no response from the students and the teacher ended the lesson by talking about the theme of the next lesson. Similarly, teacher TC2 concluded the lesson by asking students to attempt one question individually. After ten minutes students were asked to report their answers orally to the whole class. The question appeared to be difficult to all students and the teacher gave some hints on the blackboard, which helped students come up with the correct answer. Like teacher TC1, teacher TC2 ended the lesson by asking if there were any questions. There was no response and the lesson ended. In both classes no homework assignment was assigned to students.

Overall findings from the classroom observations in experimental and control classes

Comparison of findings from the classroom observations between the experimental and control classes was based on the results summarized in Table 5.3 and 5.4. Overall, the results of the two classes showed big differences in the types of learning activities, classroom interaction patterns, teaching styles, and ways in which the lesson activities were concluded. In the experimental classes the classroom climate was more active than that of the control group. Students in these classes were actively involved in the lessons through hands-on activities and worked collaboratively in small groups. The results show that there were good interactions between students and teachers during the activities through student initiated questions. On the other hand, the results show that in the control classes, students appeared to be somewhat passive, listening and copying notes from their teachers. No hands-on activities as well as teacher demonstration of experiments were observed in these classes. In all the lessons observed, lessons were conducted through whole class teaching supplemented by teacher-led questions.

5.4.2 Teacher opinions about the msce approach

Teacher opinions about the MSCE approach were gathered through the reflective interview conducted after the lesson observation series. The interview with teachers focused on their opinions about their introduction to the MSCE approach and preparation of student practical, conducting practical work with the approach. and its impact on student learning.

General opinions of the msce introductory workshop

Teachers' opinions about the MSCE interactive preparation workshop were generally very positive. The interview responses show that teachers found the workshop very useful because it exposed them to new ways of conducting practical work for students. Both teachers indicated that the opportunity to practice and reflect on the experiments before classroom application was one of the main advantages of the workshop. Similarly, teachers indicated that having access to the support materials one week in advance (both teacher and student guides) was very helpful for the preparation of lessons in general. They cited micro-scale experiments on dissolution and precipitation processes, and on the identification of unknown ions as examples of new ideas they learned from the orientation workshop. They also indicated that through the workshop they learned that it was possible to present practical work to students with small amounts of chemicals and without sophisticated equipment. However, teachers felt that there were too many activities for a one-day workshop. Table 5.5 provides a summary of individual teacher opinions about the MSCE preparation workshop.

The results in Table 5.5 show that teachers learned a lot from the introductory workshop about chemistry and practical skills. Both teachers felt that the workshop introduced them to a new, interesting, and useful idea for doing experimental work with students within resource constraints. Likewise, teachers felt that through the workshop they enhanced their chemistry knowledge and practical skills. While teacher TE1 felt that he learned more about dissolution and precipitation process from the workshop, teacher TE2 indicated that the workshop experience had increased his skills in preparation of reagents and improvisation of apparatus. Teacher TE2 indicated also that he learned about the organization and timing of practical activities from the lesson materials. The interview responses also revealed that both teachers were very happy to see that all experiments they had prepared worked well for the students during classroom implementation. Similarly, teachers indicated that the support materials were very clear, easy to understand, and helped them implement the topic in class. On the other hand, both teachers indicated that a one-day workshop was not enough for introduction to the new approach and preparation of practical lessons. Teachers felt that a two-day workshop would be better—one day for preparation of reagents and trial of experiments, the other for discussions and reflections on the lessons.

Table 5.5 *Teacher opinions about the workshop*

School	Teacher	Teacher opinions
ES1	TE1	▪ Learned a new, interesting, and very useful idea ▪ Lesson materials were very clear and easy to understand ▪ Lesson materials helped me teach the topic in class ▪ Learned a lot about dissolution and precipitation process ▪ Trying out experiments beforehand increases confidence to do it in the class with students ▪ One-day workshop for introduction, preparation, and reflection is not enough ▪ Preparation was successful, most experiments worked out very well
ES2	TE2	▪ Introduced to a good and new way of conducting experiments with students ▪ Learned about improvisation skills ▪ Increased skills of reagent preparation ▪ Increased understanding of chemistry concepts (e.g. dissolution, precipitation) ▪ Learned about structuring of practical lessons (organization of materials and equipment) ▪ Lesson materials were well structured and easy to understand, made preparation of lessons easy ▪ Plastic pipettes not reliable (busting of the 'bulb' during experimentation) ▪ Better for each group to have a set of chemicals ▪ One-day workshop for introduction, preparation, and reflection is not enough

Opinions about the usefulness of micro-scale experiments in conducting practical work

Teachers indicated that they found micro-scale experiments a useful way of conducting practical work because the micro-scale approach enabled them to do practical chemistry with a large number of students using minimum resources. Elaborating on what he thought was the advantage of the MSCE approach with respect to practical work, teacher TE1 explained that:

> *'MSCE uses less reagents and cheap equipment; it is easy; you can just manage to teach a large class with a few reagents and apparatus. Plastic sheets are simple and manageable; you don't need to have a computer print out for the reactions grids. You can easily draw on a plain sheet of A4 paper, label and make copies for students'.*

Teacher TE1 explained also how the MSCE approach could be particularly useful at his school by highlighting the advantage of using small quantities of chemicals for large number of students: *our school has 350 students in Form 5 only, …with micro-scale experiments, we have discovered that we can prepare solutions using 1 g of the material for this number of students and do practical work with cheaper apparatus. Before the introduction of MSCE we could not prepare reagents using 1g of chemicals for 350 students.*

Teachers' reflections on lesson implementation indicated that the MSCE approach was very helpful in engaging students actively in the learning process. Teachers explained that they observed students in small groups allowing each member to do the experiments with the new approach and that most students were very curious about the results of their experiments. The typical questions asked by students include: *why do some precipitates keep changing colours, why do some precipitates form fast and others form slowly, why some mixtures produce bubbles* and *why other are just clear solutions.*

When asked what they thought about group work, the teachers explained that group work was very successful. Teacher TE1 indicated that the group arrangement suggested in the exemplary materials had worked very well in class. He cited high interaction among students, in small groups as one of the successes of group work. About the number of students per group, the teacher said four students per group were reasonable for the size of the class and the laboratory space. Besides, the teachers indicated that there was no complaint from the students about the group size. Both teachers explained that by circulating amongst the groups and talking to students they found that most groups knew what they were doing, except in one lesson, where some students indicated that they did not understand why they were asked to do predictions and explanations of their experiments. Apparently, these students were not aware that making predictions was part of the practical activity. Teachers also indicated that with the MSCE approach they learned that it is possible to do pre-lab exercises, because the actual performance of micro-scale experiments takes relatively shorter time compared to the traditional approach where time is always a limitation. While group work was very successful in school ES1, teacher TE2 indicated that, although MSCE activities engaged the students very actively in the learning process, supervision of activities was not easy for one teacher because of the active participation of so many small groups. Most groups needed support/facilitation at the same time. Besides, teacher TE2 pointed out that in some groups students poured away the reagents after they had finished the experiment, thereby causing other students to move around searching for chemicals.

As for what would be the benefits and difficulties of implementing the MSCE approach in their chemistry curriculum, both teachers thought that micro-scale experiments would be suitable for teaching inorganic chemistry because there are many concepts which could be demonstrated practically to students but which are usually taught theoretically. Other benefits of micro-scale experiments include inexpensive apparatus, easy disposal of reaction products, time saving, and the flexibility of the approach (can be used in an ordinary classroom and with even lower classes).

The interview responses also showed that teachers perceived some limitations to the MSCE approach, including the difficulty of using plastic sheet techniques for experiments that require the addition of excess reagents, heating, and titration.

Opinions on the usefulness of msce in teaching solubility and solubility product lessons

Both teachers explained that they normally teach the topic of solubility and solubility product without involving students in any practical work (experiments) and that students have problems understanding even the terminology of chemistry (e.g. soluble, slightly soluble, insoluble, precipitate, dissolution, and solubility product). The teachers indicated that by involving students in experiments they helped them understand these concepts better than reading or being taught without experimenting for themselves. Teacher TE1, for example, stated that before the MSCE experience he had difficulties introducing students to the concept of solubility product constant, but after being introduced to MSCE he found it easy because of how many examples from the experimental results could be used to introduce the concept to students. Likewise, the teacher indicated that students could easily relate examples of dissolution and precipitation process to the solubility equilibrium of a sparingly soluble salt.

Perceived impact on student learning: overall picture

Overall, teacher responses indicated that the MSCE approach had some impact on student learning in the cognitive and affective domains. Teachers mentioned that students' own experiences with micro-scale experiments helped them link the chemistry ideas they are taught to what they saw with their own eyes. Specifically, teachers felt that the micro-scale based lessons helped students learn the solubility of various salts in a very short time, including basic solubility concepts of soluble, insoluble, and slightly soluble substances. Teachers also mentioned that students were able to relate the phenomena observed during the practical work to theory, such as dissolution and precipitation reactions. In the affective domain, teachers said that most students appeared to be interested in the experiments and enjoyed the lessons as well as working in small groups.

Responding to what he thought students had learned from the MSCE lessons, teacher TE2 explained: *"Actually science involves experiments. When students do experiments, observe what happens and talk about what they have seen, they are likely to understand better rather than talking a lot but in the "air". You talk about dissolution, soluble, slightly soluble, and insoluble, precipitation reaction and solubility product and do many calculations, then the topic is finished. Practical work is done in another year or it is not done at all. This makes connections between theory and practical work very difficult. In MSCE lessons we did practical together with theory. Students saw how particles were disappearing (dissolving) in water and also they saw solid appearing out of the solution (precipitation). This helped me to explain easily dissolution and precipitation reactions as well as the concept of solubility product".*

A similar response, though brief, was also offered by Teacher TE1: *"obvious, students learned a lot from the MSCE approach; they learned solubility concepts both by theory and practical. They did experiments; they discussed their observations together and generated some very good conclusions about solubility rules for ionic compounds".*
The above responses indicate that the MSCE approach provided students the opportunity to relate what they are told about the meanings of various chemical terms/concepts by teachers or what they have read in textbooks with what they experienced or observed it practically.

5.4.3 Student experiences with the msce approach: questionnaire responses

Data obtained from student questionnaires provided an inventory of student experiences and opinions about learning chemistry with the MSCE approach. The responses of the questionnaire are presented following students' reactions to the MSCE approach general activities and to specific classroom learning activities.

Experiences and opinions about practical lessons with msce approach

Student responses to the close-ended questionnaire items were analyzed quantitatively in order to get information on how students reacted to different items, focusing on the overall classroom experiences of the MSCE approach. Table 5.6 presents the results of students' reactions to the MSCE practical activities from the students in the experimental schools.

Table 5.6 *Students' opinions about MSCE practical lessons (N = 83)*

Did you feel that Micro-Scale Chemistry practical activities:	N[a]	Mean[b]	Standard deviation	Agreed or strongly agreed in %
1. Were linked to other parts of chemistry	77	3.9	0.94	70.2
2. Helped you understand more about solubility and precipitation	83	4.7	0.53	97.6
3. Helped you understand more about qualitative analysis	81	4.2	0.75	88.9
4. Made you feel like learning more about the subject	82	4.2	0.77	90.2
5. Helped you prepare for other topics in the syllabus	82	3.8	0.96	73.2
6. Clarified some of concepts that you had difficulties with	83	4.2	0.76	90.3
7. Made you enjoy your chemistry classes	83	4.5	0.50	100.0
8. Made your head think	83	4.2	0.81	91.4
9. Have given you confidence to carry out experiments by yourself	83	4.4	0.72	91.6
10. Provided you with the opportunity to use materials & equipment	82	4.0	0.85	81.7
11. Made you feel like a Chemist	83	4.3	0.75	91.4
12. Made you actively participate in the lesson	83	4.4	0.62	95.2
13. Increased your co-operation and sharing ideas with fellow students	83	4.5	0.61	96.4
14. Made you feel very responsible about safety and environment	83	4.0	0.86	85.9
15. Exposed you to an easier way of conducting experiments	83	4.4	0.77	90.4

Note: Na = number of respondents per item; b5-point scale (1 = strongly disagree, 5 = strongly agree).

Overall, the results in Table 5.6 clearly demonstrate that students reacted positively to the MSCE practical activities. The very high mean scores (ranging between 3.8 and 4.7) for all 15 items suggest that the majority of students had very positive experiences with the practical work carried out in the micro-scale approach. The results also show that there were many discrepancies in student reactions to the MSCE activities (standard deviation is less than 1 for all 15 item scores). Students' reactions to specific statements have been organized into three categories: enhancing learning of chemistry; cooperation and enjoyment in the subject; and laboratory learning skills and safety.

Enhancing learning of chemistry

The results in Table 5.6 show that students who experienced chemistry lessons taught with MSCE were convinced it helped enhance their learning of chemistry. About 98 % of the students either agreed or strongly agreed that lessons held conducted with the MSCE approach helped them understand more about the topic of solubility and precipitation. Nearly 89% of the students agreed that the activities helped them understand more about qualitative analysis of ionic compounds, and about 90% of the students felt that the MSCE activities made them feel like learning about the subject more. The students' positive feelings about learning through micro-scale chemistry experimentation are further revealed by the more than 90% who found the activities helpful in clarifying their difficulties with some chemistry concepts. About 73% of the students agreed that the MSCE activities helped them prepare for other topics in the syllabus and only 70% of the students agreed or strongly agreed that the MSCE activities were linked to other parts of chemistry.

Cooperation and enjoyment in the subject

Table 5.6 shows that all 83 students (100%) who completed the questionnaire found chemistry classes with micro-scale chemistry experimentation enjoyable. Students' enjoyment is further revealed by their active participation during the lessons. More than 95% of the students indicated that MSCE practical activities made them actively participate in the lessons. Moreover, students' positive attitudes toward chemistry are indicted by the nearly 92% of students who agreed that their exposure to MSCE practical activities made them feel like chemists. In terms of collaboration, about 96% of the students agreed that working collaboratively in small groups increased cooperation and sharing of ideas among themselves and with their teachers.

Laboratory learning skills and safety

Nine out of every 10 students felt that micro-scale chemistry experience gave them the confidence to carry out experiments by themselves and that it exposed them to an easy way of conducting experiments. Besides increased confidence in doing experiments, more than 85% of the students thought that exposure to micro-scale experiments increased their awareness of safety and environment as well as providing them with the opportunity to learn practical skills.

Students' opinions on specific classroom-learning activities of msce lessons

The second part of the student questionnaire focused on students' opinions about specific classroom-learning activities including pre-lab exercises, prediction, conducting experiments, analysis and discussion of experimental results, and follow-up assignments/homework. The means and standard deviations were computed for each item to designate student opinions on the usefulness of each of the above activities in learning the subject. Student responses to these items are presented in Table 5.7 under pre-laboratory work, group practical activity, post-lab discussions, and follow-up assignments.

Table 5.7 *Student' opinions on specific activities of the MSCE lessons*

How useful have you found the following activities in helping you learn chemistry with Micro-Scale Chemistry approach?	**N[a]**	**Mean[b]**	**Standard deviation**	**Helpful or very helpful in %**
Pre-laboratory work				
1. Doing pre-lab exercises	83	4.0	1.02	78.3
2. Teacher not explaining everything in the activity	82	2.5	1.28	26.8
Small group practical activity				
3. Predicting what will happen in a particular experiment	81	3.9	0.86	76.5
4. Doing experiments myself	83	4.4	0.99	85.6
5. Using instruction from the student worksheet	82	3.9	1.05	73.1
6. Using plastic sheets to perform experiments	82	4.3	0.91	86.6
7. Using grid paper to record observations	83	3.9	1.00	78.3
8. Analyzing and explaining experimental results	83	4.2	0.85	84.4
Post-lab discussion				
9. Discussing experimental results in small	82	4.4	0.91	87.6
groups	83	4.0	1.20	72.3
10. Discussing experimental results as a whole				
class	83	4.0	1.19	69.9
11. Teacher explaining the chemistry behind each experiment				
Follow-up assignment				
12. Doing homework myself	83	4.6	0.81	90.4

Note: Na = number of respondents per item; bMean on 5 –point Likert scale (1= not helpful at all, 5 = very helpful).

Overall, the results in Table 5.7 show that the students' classroom experiences with most of the MSCE activities were very positive. One notable exception is the attitudes of students towards the teacher's role--27% felt that it was of little help for the teacher not to explain everything in the activities. On the other hand, about 78% of the students found pre-laboratory exercises very helpful in consolidating their learning of the subject.

Students' experiences with small group practical activities show that more than 80% found doing experiments by themselves, using a plastic sheet to perform experiments, and analyzing and explaining experimental results very helpful in learning the subject. Similarly, about 75% of the students felt that making predictions, using instructions from the student worksheet, and using grid paper to record observations facilitated their learning of chemistry. Students also reacted positively to post-lab discussion in small groups (88%), discussion with the whole class (72%), and teacher explanation of the chemistry behind each experiment (70%). Students' positive experience with the MSCE based lessons is also reflected in their attitudes to follow-up assignments (homework). About 90% of the students found follow-up assignments very helpful in consolidating their learning.

In addition to the closed-ended items, the student questionnaire had three open questions, for which students were asked to write down two aspects they liked (or disliked) most about the MSCE based lessons as well as the differences between MSCE classes and the normal chemistry classes. Student opinions here corroborate most of the findings obtained from the close-ended items, but also provide supplementary information on their experiences with and feelings about the MSCE approach. Table 5.8 shows the aspects students liked and did not like about the MSCE-based lessons, sample reasons, and the frequency of response.

About 2/3 (51; 67 %) of the students liked doing experiments with the plastic sheet because it was simple, interesting, and fast compared to using beakers and test tubes. Students stated that using plastic sheets enabled them to do many experiments at the same time with little amount of chemicals and observe reaction products clearly. Moreover, students felt that performing experiments on the plastic sheet minimized their movements in the laboratory during the practical.

Half of the students (38; 50 %) (Table 5.8) described doing experiments themselves and observing different reactions as one aspect they liked most about the MSCE approach because it helped them understand more about chemistry and gave confidence in practical work, made them think critically, and helped them to understand well the concepts of solubility and precipitation. Similarly, 14 students (18.4%) indicated that they liked observing colour changes and formation of precipitates during the practical because it was fascinating, helped them to learn more about the topic, and made them enjoy the lessons. Besides their enjoyment, students found that colour changes and formation of precipitates helped them recognize if a reaction occurred or not, and in differentiating between soluble and insoluble salts in water.

Table 5.8 *What students liked and did not like about MSCE lessons (N= 76): an overview*

What they liked	Sample reasons why they liked this aspect	Frequency (in %)
Using plastic sheet	– Interesting and simple method to use compared with beakers and test tubes – More accurate observation than the test tube due to cleanliness of the plastic sheet – Enabled to do many experiments in a short time and with little amounts of chemicals	67.1
Doing experiments by myself (ourselves)	– Helped to know more about chemistry and provides confidence in practical work – Led us to think critically and increase our reasoning ability	50.0
Pre-lab exercises and making prediction of an experiment	– Helped me prepare well for the practical – Made us think more about the experiment we are going to do	26.3
Discussion of experiments in small groups	– Increased cooperation and sharing of ideas with classmates – Each member participated actively in discussing the observations	22.4
Colour changes and precipitate (and bubbles) formation	– It was wonderful to see how colours were changing – Helped to know that reactions occur and that precipitation formed during the reaction is due to formation of insoluble substances	18.4
Follow-up assignment and home work	– Helped me to 'measure' whether I was serious or just enjoyed going to the lab. Increased level of understanding of the subject matter	11.8
Whole class discussion	– Helped to share ideas with different people from different groups and get immediate feedback from the teacher	7.9
What they did not like	**Sample reasons why they did not like this aspect**	
Exposure of chemicals on the sheet	– Possibility of contamination and risk for students' health – Frequent colour change due to further reaction due to air oxidation – Boxes on the grid paper are small	19.7
Sharing of apparatus and chemicals	– Some students were not careful and systematic. Mixed droppers for different reagents. Others poured away solution after use.	14.5
Precipitate/colour changes	– I can not see what takes place in the reaction. Precipitates are too small	7.9
Lack of safety materials	– Dangerous to use the plastic sheets without protective gear (gloves)	5.2
Pre-lab exercise	– Spent a lot of time answering pre-lab questions and did not have enough time for doing the practical	3.9
Competition	– Different students gave different views and each one held his/her ideas	3.9

Preparing students for the practical activities involved doing pre-laboratory questions. 20 (26 %) students described doing pre-lab exercises as the activity they liked most because it prepared them well for the practical. They stated that engaging in pre-laboratory exercises was very useful in making them aware of and think more about the experiments they were going to do. As a result they knew the experiments very well, which enabled them to participate actively during the lesson.

Another thing students liked about MSCE lessons was opportunity to work collaboratively in small groups. 17 (22.4%) students indicated that they liked discussions held during small group practical activities because they increased cooperation and sharing of ideas; increased interaction among students and between students and teachers; helped them recognize where they did well and where they went wrong; allowed each member to participate actively in discussing the observations; and helped them understand more about the topic. A few students (7.9%) indicated that they preferred to discuss results in a whole class set-up because they could share ideas with different people from different groups and get feedback from the teacher at the same time.

However, a few students expressed that they did not like discussing experiments in small groups because in some groups there was an element of competition among members, and it was sometimes difficult to reach a consensus. Similarly, three students mentioned discussing as a whole group was not good because it did not allow full participation of all students.

Students also felt positively about doing homework as a follow-up assignment. Nine (12%) students indicated that they liked homework because it helped them to check whether they had learned anything from the practical or just enjoyed going to the lab; and it forced them to read more about chemistry, which increased their level of understanding. In addition, students explained that they liked doing homework because it helped them make revisions on the experiments they conducted.

Apart from the positive reactions students had about different aspects of MSCE activities, a few mentioned that they were not happy about certain aspects of the approach. Fifteen students (19.7%) felt that exposing many drops of chemicals on the surface of the plastic sheet was not safe because some chemicals were toxic and could endanger their health. Similarly, nine students (11.8%) stated that they did not like sharing chemicals among small groups because some students were not careful in the use of droppers, and as a result they contaminated the reagents, which made interpretation of their experimental results very difficult. A few students (5.2%) stated that they did not like doing the experiments without enough safety materials, such as gloves to protect them from hand contamination.

Student opinions about the differences between msce and normal chemistry lessons: open questionnaire response

Students of the two schools indicated that in their normal classes they had been studying chemistry theoretically (without practical work) since the start of their Form 5 while the MSCE lessons involved both theory and practical. The following responses illustrate students' feelings about their classroom experiences with MSCE lessons as compared to regular chemistry classes:

> *"In MSCE we did a real practical rather than the alternative to practical we are doing in the normal chemistry class".*

> *"In my regular chemistry lessons I have to agree when taught without seeing the results. After doing the MSCE activities, I have seen the results myself by doing experiments and I enjoyed a lot".*

Similarly, students felt that MSCE lessons involved them more in doing and thinking than normal classes because they had to do the practical and think about the results (theory) at the same time. The second difference student expressed related to the type of apparatus used for practical work. Students indicated that the apparatus used in MSCE (e.g. plastic sheet) were different from test tubes and beakers, which are used in normal practical lessons. In addition, students mentioned that while in normal practical classes the breaking of apparatus was a common, in the MSCE lessons there were no breakages due to the nature of the apparatus.

In terms of learner participation, students' feelings revealed that there was a difference in the nature of student participation and interaction in the two approaches. They identified high interaction among students, students and materials, and students and their teachers as another major difference between MSCE lessons and normal classes. They indicated that in the MSCE lessons each student actively participated in the lesson, the teacher was available for help, and they were very free to express their ideas. The following responses illustrate this:

> *"In MSCE lessons, we were free to ask questions and express our ideas, while in normal classes we are not always free because, when we ask questions, our teachers normally think we make unnecessary challenges and when we want to express what we understand our fellow students think that we are proud of ourselves".*

> *"These lessons were so different because there was good cooperation between students to students and also between the teacher and students so you can find it is so interesting and gives the student the courage not to, miss the lesson or period different from our regular chemistry class".*

Moreover, students from the two schools indicated that the quality of observation in MSCE experiments was better because the results of reactions could be easily seen and compared on one plastic sheet than in several tests tubes. Other differences include the use of pre-lab exercises and grid paper to record the observations in the MSCE lessons, which students did not experience in their regular chemistry lessons.

5.4.4 Student experiences with the msce approach: interview responses

Students' learning experiences with micro-scale chemistry experimentation were also explored through interview. Analysis of the interview data yielded information similar to what was obtained from open-ended questionnaire items. There was not a great deal of disparity in opinion about the MSCE approach between the students of the two schools, and their responses have been pooled together under four categories: student general impressions about MSCE, student favourite activities and perceived learning from MSCE lessons, student perception of the benefits of group work and teacher support, and differences between MSCE lessons and regular chemistry classes.

Students' general opinions about the msce approach

Overall, students' impressions about the use of micro-scale chemistry experimentation to conduct practical work were very positive. Students from both schools described the method as a good, interesting, and cheap way of doing experiments. When asked further about what was good and interesting about the method, students explained that they found the method easy to understand, that it gave interesting results, was easy to clean up after, and was less dangerous (no breaking of apparatus), and that it simplified practical work compared to other methods, such as using many test tubes and beakers. In addition, students described the approach as less expensive (few simple apparatus, little amount of chemicals, and short time) compared to the standard methods of using beakers and test tubes. On the other hand, students pointed out that the use of plastic sheets was not suitable for experiments requiring heating and testing of gases.

Student favourite activities and perceived learning with msce lessons

During the interview, students mentioned doing experiments themselves and making observations as their favourite activities. Specifically, they mentioned the experiments involving mixing lead nitrate and potassium crystals in a water drop (experiment 2; lesson 1) and mixing different solutions of cations and anions using one drop (experiments in lesson 2) on the surface of plastic sheet. Students felt these experiments provided them with many valuable learning experiences concerning solubility of different salts in water. They indicated that by observing colour changes and formation of precipitates they were able to recognize which substances were soluble or insoluble in water. Secondly, students explained that the experiments helped them understand the dissolving and precipitation process. Through the experiment of lead nitrate and potassium iodide crystals in a water drop, students felt that they were able to 'witness' how ions move. As one student wrote: *"we placed the white crystals of the two salts at the edge of water drop from different sides, we saw them disappearing in water and after sometime a yellow solid appeared at the middle of the water drop".*

Another student gave a similar response, illustrating what students found interesting in doing the experiments. *"I appreciated the movement of ions during a certain experiment where the ions met at the centre of water circle". I got excited to see a nice yellow precipitate forming at the centre of water drop".*

When probed further about what was interesting in those experiments, students said "observing colour changes and precipitate formation" because it helped to identify which compounds were soluble and which were not in water. Through micro-scale experiments students indicated that they learned the solubility of many salts in a short time. Students mentioned the identification of unknown ions, separation of ions by selective precipitation, and solubility product as some of the concepts they learned from the MSCE lessons. The following two responses illustrate a student's feeling about what she/he learned from the MSCE practical activities. *"…, I can say that I have learned much because I have been hearing about solubility and precipitation, but I have never come across any experiment about these concepts, therefore after doing the experiments, I think I can explain what it is ….even other types of solubility, I can understand".*

> *"I learned that it is possible to do a lot of experiments with simple apparatus within a short time. For example, in lesson two, we performed a lot of experiments and we were able to recognize which ions form soluble and insoluble salts, by looking at the precipitates formed and the clear solutions."*

Student perceived benefits of group work (small group-learning) and teacher support

In the interview, students from both schools felt that small group activities had been very useful because they allowed them to discuss freely about their work and everybody participated actively. Through group work, students stated that they were able to share ideas with classmates, which enabled them to come up with solutions to problems they faced. They explained that in some lessons it was difficult to reach consensus, but with help from the teacher they managed to agree. They stated that teachers were very supportive, open to questions, and friendly. When asked to give an example of what aspects/experiments made it difficult for them to come to consensus, students mentioned identification of unknown compounds (lesson 3). They explained that it took them a long time to find solution to the question because they could not easily agree on the identity of the compounds.

Students also indicated that they learned a lot from working in groups, as the following typical response illustrates: *"…concerning the identification of ions, one thing which I had difficult in understanding is the process of selective precipitation, but after we discussed with my friends in the group, I now understand it".*

Despite the advantages of group work students expressed some dissatisfaction related to cooperation with their classmates. Students from school ES2 in particular mentioned sharing of chemicals and droppers among small groups as aspects of the MSCE lessons they did not like because not all students were keen on following the instructions. Some groups were not careful and contaminated the reagents, which made analysis of the results very complicated. Likewise, students from this school indicated that there was an element of competition either between members in the group or between small groups.

What students would like more or less of in chemistry lessons

Students offered different opinions about what they would like more of in chemistry lessons. Some students wanted more practical work because it helps them understand many of the abstract concepts of chemistry; others preferred more theory because more practical work means more exposure to hazardous chemicals. Likewise, others indicated that they would like more problem solving exercises, because they increase their understanding of the subject. Others said that they would prefer more practical, but only after being introduced to basic concepts in theory sessions so that they know what the experiments are all about. As to what they would like less of, students said that the content of their A-level chemistry was too long to be covered in two years, and that they would prefer the time on theory sessions to be reduced. They specifically mentioned that there were too many elements/topics to study at their level. Similarly, they indicated that with MSCE lessons, there were too many reagents on one grid paper and that reducing the number would help reduce the possibility of contamination.

5.4.5 Impact of the msce approach on cognitive learning

The impact of the micro-scale chemistry approach on student cognitive learning was measured by a knowledge test administered before and after teaching of solubility and precipitation lessons. Pre-test and post-test results have been analyzed on an item level. In this section, the results of the multiple choice items will be presented first, followed by the results of the two short answer questions.

Multiple choice items

The knowledge test consisted of 13 multiple choice test items. An analysis of the pre-test and post-test data showed that for only five items could a significant learning gain be determined for either the experimental or control group. It was decided to focus on these five items. Box 5.1 provides an overview of these five multiple choice items and two short-answer items (see next section), and in Table 5.9 the results of the analysis are presented. A Chi-square test analysis showed a significant learning gain for the experimental group for items 1, 7, and 9 (see Table 5.9). For the control group a significant learning gain could be determined for item 4 and item 13 (see Table 5.9). A content analysis of the five multiple choice items revealed that items 1, 7, and 9 in particular reflected the MSCE approach. These items emphasized application of chemistry concepts and principles to solve a given problem (based more on chemistry processes than content). Items 4 and 13 reflected knowledge that is typically acquired in a more traditional lesson. These items emphasized understanding of specific chemistry concepts and their relationship.

Short -answer items

A t-test was used to examine learning gain on the short-answer items of the experimental and control group. Comparison between the experimental and control group gain showed that for all items, except one (item 15c), a significant difference could be established in favour of the experimental group (Table 5.10). This meant that students from experimental classes significantly improved their scores after learning the topic as compared to those from the control classes. On the other hand, the results showed that although both groups did improve their scores on item 15c, the difference in gain between the two groups was not large enough to be statistically significant. The results for item 15c could possibly be explained by the following reasons: (1) the concept tested was easy and students from both groups could easily learn by heart (2) the nature of the item probably gave students a clue to the right answer, because it involved choosing between two responses, without demanding a supporting argument.

Box 5.1 *Selection of USPT multiple choice and short-answer items used in the analyses*

1. If powder soap (for example, Foma) is mixed with water, a soap solution is obtained. Which process below correctly summarizes this situation?
a. Solution c. Precipitation
b. Dissolution d. Solubility

4. One of the following chemical concepts/ terms describes the normal maximum quantity for solute in a solvent (expressed in---grams/100grams of water) at a certain temperature.
a. Solubility c. Solute
b. Solvent d. Concentration

7. A solution which contains only <u>one</u> of the following cations—Mg^{2+}, Pb^{2+}, or NH_4^+--is tested with the following reagents and the following results are obtained:

Reagent	**Results**
0.1 M Na_2SO_4	Precipitate
0.1 M NaI	Precipitate
0.1 M $NaNO_3$	No precipitate

This cation is:
a. NH_4^+ c. Mg^{2+}
b. Pb^{2+} d. Na^+

9 When a potassium iodide reagent is added to a neutral unknown solution a yellow precipitate forms immediately. What might the unknown solution be?
a. Calcium (II) nitrate c. Lead (II) nitrate
b. Iron (III) nitrate d. Barium (II) nitrate

13. Two solutions of equal volumes are mixed, one containing Ag^+ and the other Cl^-. If, at the instant of mixing, $[Ag^+]$ is 10^{-3} M and $[Cl^-]$ is10^{-3} M, which one of the following statements is true? (Ksp for AgCl is 1.8 x 10^{-13})
a. A precipitate forms because Q is less than Ksp.
b. A precipitate forms because Q is greater than Ksp.
c. No precipitate forms because Q is equal to Ksp.
d. No precipitate forms because Q is greater than Ksp

NOTE: Q stands for ion product and K_{sp} stands for solubility product constant.

14. A solution contains Ba^{2+}, Fe^{3+}, Ag^+, and K^+. What compounds (give correct formula for each compound) could be added, and in what order, to separate these ions from the mixture. What ion will remain in the solution at the end of the separation process?

What compound could be added?		Represent what you would see happening by a net chemical equation.
a	1st	
b	2nd	
c	3rd	
d	4th	

14e. Explain why would you follow the order of addition from 1st to 4th in order to separate the four ions from a mixture?

15. a. What is the difference between <u>solubility product</u> and <u>ion product</u>?
b. Barium sulphate, which is opaque to X-rays, is used for the "barium meal" to enable X-ray pictures to be taken of the gut. Barium ions are very toxic; why is this not a problem here?
c. Will the solubility of Barium sulphate in a solution of 0.25 M Na_2SO_4 be greater or lower than that in pure water?

Table 5.9 *Differences between pre- and post-test performance on multiple choice items for the experimental and control groups***

		Experimental (N=88)			Control (N=107)		
		% of correct responses		*Sign. (χ^2)*	*% of correct responses*		*Sign. (χ^2)*
Item	**Item category**						
1	*Comprehension*: measures students' ability to grasp meaning of dissolution and relate it to real life situation. [Practical oriented and reflects MSCE approach]	Pre Post	8.0 37.5	0.351*	Pre Post	11.8 20.4	0.117
7	*Application /analysis*: measures students' ability to apply solubility rules and experimental data to solve a given practical problem. [Practical oriented and reflects MSCE approach]	Pre Post	47.7 79.5	0.331*	Pre Post	59.0 62.2	0.032
9	*Application/ Analysis*: measures students' ability to analyze possible chemical reactions and apply solubility rules to make conclusions regarding precipitation. [Practical oriented question and reflects MSCE approach]	Pre Post	31.8 61.4	0.296*	Pre Post	34.2 39.8	0.058
4	*Knowledge*: measures ability to recognize correct definitions of chemical terms or concepts. [Reflects regular teaching approaches]	Pre Post	40.9 53.4	0.125	Pre Post	50.3 76.5	0.265*
13	*Comprehension*: tests students' ability to remember and use relationships between chemical concepts to predict occurrence of precipitation. [Reflects regular teaching approaches]	Pre Post	52.3 55.7	0.034	Pre Post	54.0 73.7	0.058*

Note: *Statistically significant ($p < 0.05$); ** differences based on items with significant gains.

Table 5.10 *Differences between pre- and post-test performance on short-answer items for the experimental and control groups*

		% students that answered the item correctly						
		Experimental (n=88)			Control (n=107)			
Item	Item characteristics	*Pre-test*	*Post-test*	*Gain*	*Pre-test*	*Post-test*	*Gain*	*P**
14a	*Application*: measures students' ability to apply chemical principles and rules to solve a problem; and represent chemical processes in an appropriate scientific language. [Reflects the MSCE approach]	2.3	44.3	42.0	5.7	9.4	3.7	0.000
14b	*Application*: measures students' ability to apply learned concepts and principles as well as ability to represent chemical processes in an appropriate scientific language. [Reflects the MSCE approach]	2.3	37.5	35.2	4.7	7.5	2.8	0.000
14c	*Application*: measures students' ability to apply chemical principles and rules to solve a problem; and represent chemical processes in an appropriate scientific language. [Reflects the MSCE approach]	2.3	28.4	26.1	3.8	3.8	0.0	0.000
14d	*Application*: measures students' ability to apply chemical principles and rules to solve a problem; and represent chemical processes in an appropriate scientific language. [Reflects the MSCE approach]	1.1	30.7	29.6	3.8	1.9	-1.9	0.001
14e	*Analysis*: measures students' ability to make and defend a scientific argument from given data. [Reflects the MSCE approach]	2.3	17.0	14.7	1.9	1.9	0.0	0.003
15a	*Comprehension*: measures students' ability to identify the distinguishing property between two closely related concepts/terms. [Reflects regular teaching approaches]	1.1	23.9	22.8	8.5	17.0	8.5	0.027
15b	*Application*: measures students' ability to interpret and use solubility rules to life-related situations [Reflects both teaching approaches]	12.5	33.0	20.5	12.3	17.9	5.6	0.026
15c	*Comprehension*: measures ability to recognize relationships between given concepts and use it to explain a problem [Reflects regular teaching approaches]	10.2	34.1	23.9	21.7	34.0	12.3	0.129

Note: *Significant ($p < 0.05$) difference in learning gain between the experimental and control group.

5.5 CONCLUSIONS

This chapter has presented the design and results of the field test carried out to evaluate the impact of the MSCE on teaching and learning of chemistry in Tanzanian A-level classes. The impact of the MSCE approach was assessed by looking at the actual classroom implementation of the approach, the opinions of teachers about the approach, student experiences, and student learning outcomes from MSCE–based lessons. The impact of the approach in terms of student cognitive learning was determined by comparing the learning outcomes between students taught *Solubility and Precipitation* with MSCE practical activities with those taught the same topic by using teaching methods teachers normally use.

In general, the results of the evaluation show that both teachers and students had positive experiences with the micro-scale chemistry experimentation approach. They both liked the approach, were able to implement it in class, and found the approach helpful in facilitating their teaching and learning of chemistry.

Results from classroom observations show that the use of micro-scale practical activities promotes an active learning environment. It provides opportunities for student-student interaction by allowing more time for discussion and reflection as actual performance of experiments is completed fast. It also fosters cooperative learning elements among students as well as stimulating students' interest in the subject.

Teachers' opinions about the MSCE approach show that they found experimenting on a micro-scale interesting and useful for conducting practical work with students. The approach provided them the opportunity to do practical work with large numbers of students using minimum resources and had a great potential to engage students actively in the learning process through small group activities. Teacher reflections also indicated that their exposure to micro-scale chemistry techniques enhanced their subject matter knowledge as well as practical skills.

Results from questionnaires and interviews show that the majority of students experienced lessons conducted with MSCE practical activities very positively. Most students seemed to like the MSCE approach because it is simple, interesting, and makes them enjoy chemistry classes and learn more about the subject. Apart from being simple and interesting, students appreciated the opportunity to do practical work in the MSCE based lessons as compared to normal lessons, which are normally taught without practical work. Students felt that with micro-scale chemistry experimentation they were actively involved in the learning process. Apart from helping them understand more about chemistry and increase their confidence in practical work, students indicated that the experiments and follow-up questions were challenging and made them think critically. These results suggest that MSCE activities can be used as vehicle to promote thinking skills among students.

Comparison of student pre-test and post-test results at item level between the experimental and control classes, revealed two patterns of student achievement with regard to solubility and precipitation topics. Students who studied the topic with exposure to MSCE practical activities showed higher learning gains in items related to application and analysis of chemistry principles than students who studied the topic by regular methods. On the other hand, students who studied the topic by regular methods performed significantly better in factual knowledge items than the experimental group students.

Apart from the positive responses of both teachers and students to the MSCE approach, there are some concerns about classroom implementation. Some students felt that conducting experiments on the surface of the plastic sheet was not safe, since the technique exposes students to many chemicals at time, some of which are toxic and might have an undesirable effect on their health. Similarly, students felt that there was the possibility of further reactions due to air, contamination between different reagents due to small boxes, and hand contamination unless great care was observed. These findings suggest that although the approach appears to be effective in promoting student active learning and love for chemistry, safety issues and the nature of the chemicals used in the experiments might need a review.

CHAPTER 6
Discussion

This study focused on the design and evaluation of micro-scale chemistry curriculum materials to help teachers implement practical work in A-level chemistry teaching in Tanzania. The findings of this study are discussed in this chapter. After a recapitulation of the research problem and approach (section 6.1) the main findings are summarized and discussed in section 6.2. A reflection on research methodology is presented in section 6.3. In section 6.4 conclusions about the study are drawn, and recommendations are formulated in section 6.5.

6.1 RECAPITULATION OF RESEARCH PROBLEM AND APPROACH

In the middle of the 1990s a situational analysis investigated science teaching in Tanzanian secondary schools (Chonjo, et al., 1996). It became apparent that there were deep-rooted problems in the teaching and learning of science in the secondary school system. Problems in pedagogy, curriculum, examinations, laboratories, equipment, and consumables were among the most prevalent in the report. The situational analysis indicated that although most teachers appeared to have adequate subject matter knowledge they lacked competence in such methodologies as how to conduct and manage practical work. Teacher-cantered (chalk and talk) teaching methods were observed to dominate most science lessons. Access to regular INSET programmes for teachers to update their knowledge and teaching skills appeared to be limited. Likewise, the syllabuses were overloaded with content while examination requirements compelled teachers to teach in a rush to cover the long syllabus. On laboratories, equipment, and consumables, the situation was reported as critical. Resources for practical work were reported to be very limited. Practical work rarely happened in most schools because standard equipment and chemicals were too expensive to purchase.

In view of these findings, the need for improvement of the science curriculum in the secondary education sector was seen as inevitable. Improving teaching and learning materials (e.g. text books and laboratory facilities) in the schools and

strengthening both pre-service and in-service science teacher education were considered priority areas for improvement efforts. Among the improvement strategies were the establishment of collaborative donor funded science education projects aimed at improving the teaching and learning of science and mathematics in the country, including Science Education in Secondary Schools project (SESS), Science Teacher Improvement Project (STIP) and Teacher Education Assistance in Mathematics and Science (TEAMS). SESS and STIP focused on improving the O-level science curriculum by supplying schools with teaching and learning materials as well as running in-service education programmes for teachers. Although these projects appeared inspiring, thorough evaluation studies to determine their impact have scarcely been conducted in the schools (Coppard, 2004; Osaki, 1999).
The TEAMS project focused on science teacher education, both pre-service and in-service, and worked mainly with undergraduates at the University of Dar es Salaam and A-level science teachers in Tanzania. One of the activities of the TEAMS project involved research and development of teaching and learning materials, and capacity building by training science education researchers and leaders. The Micro-Scale Chemistry Experimentation (MSCE) study was carried out within the framework of the TEAMS project. The underlying assumption of MSCE is *less is more*: less costs, less demand on chemicals and equipment, less 'chalk and talk' teaching, for more understanding, more motivation, more safety, and more 'hands-on and minds-on' activities.

The MSCE study

The MSCE study was initiated to explore the possible use of simple forms of practical work in supporting an active learning environment with low demands on equipment and consumables—a promising strategy towards improving teaching and learning chemistry in Tanzanian secondary schools. Specifically, the study was set-up to introduce the micro-scale chemistry approach as a means to help teachers implement practical work in chemistry classes without the need for well-equipped laboratories, to promote the learners' interest, active participation, and learning with understanding in A-level chemistry. The study intended to design and evaluate a promising intervention of 'micro-scale experiments and the supporting curriculum materials' that can contribute to the implementation of practical work in the A-level chemistry curriculum. In line with this objective, the central research question that was explored in the study was:

> *What are the characteristics of micro-scale chemistry materials that contribute to the initial implementation of practical work in chemistry education in Tanzanian secondary schools?*

In order to answer the above question, the study adopted a development research approach. Its activities involved three stages: front-end analysis, design and development of prototypes, and evaluation of the impact of the MSCE intervention. The front-end analysis stage consisted of context analysis and a literature review. The context analysis sought to gain insight into the existing practices of science teaching in Tanzanian secondary schools with particular attention to the provision (status and constraints) of practical work in the chemistry curriculum. A review of the relevant literature sought insights into promising examples of low-cost methods of practical work in chemistry teaching. The literature review also aimed at gaining insights into the state-of-the-art-knowledge (intentions, practices, and effects) of practical work in secondary science education with a particular focus on developing countries, particularly in Sub-Saharan Africa. This first stage of the study resulted in useful information that helped formulate design guidelines for the development and formative evaluation of 'micro-scale experiments' and the supporting curriculum materials for the Tanzanian context.

The development stage involved the (re)design, formative evaluation, and revision of successive prototypes. Prototypes of exemplary curriculum materials were created in a cyclic approach of design and formative evaluation so that successive versions of the materials iterate until a satisfying final product was attained. The quality aspects of the prototypes were established through expert and user appraisals, and through classroom trial to explore the validity and practicality of the intervention. The evaluation activities also aimed at improving the prototypes in these aspects. On the basis of the evaluation results at each revision cycle (as reported in Chapter 4) suggestions for improving the MSCE intervention were incorporated into the curriculum materials, and the final version was produced for use in the field test.

The third and final stage of the study was a summative evaluation of MSCE intervention. The final version of exemplary curriculum materials was field tested to evaluate the impact of the MSCE approach on teaching and learning chemistry in the context of Tanzanian A-level classes. In order to assess the impact of the MSCE approach on student learning outcomes, a pre-/post-test quasi experimental, non-equivalent control group design was applied to compare the learning results of students taught a specific syllabus content topic via exposure to micro-scale experimental work with students who studied the topic through regular teaching methods. In the next sections of this chapter, the main findings of the study are summarized and discussed.

6.2 SUMMARY AND DISCUSSION OF MAIN FINDINGS

6.2.1 Characteristics of curriculum materials that facilitate classroom implementation

The development and use of new curriculum materials is seen as an important strategy for curriculum implementation (cf. Ball & Cohen, 1996). Curriculum materials may serve as concrete examples and support for teachers in understanding the meaning of an intervention or innovation at hand, particularly at its initial implementation phase (van den Akker, 1988; Voogt, 1993). In this study, providing clear and validated materials was considered important for successful implementation of the MSCE approach in the classroom. Overall, the exemplary curriculum materials aimed at helping teachers orient themselves to the micro-scale chemistry approach and assisting them with its initial classroom implementation.

To illustrate the specific features of micro-scale chemistry practical work, exemplary lesson materials were developed with a large degree of emphasis on structure and essential but vulnerable aspects of a curriculum (van den Akker, 1988), which promote practical work and an active learning environment. The materials provided adequate procedural specifications, i.e. accurate 'how-to' advice to help the teacher execute the lesson. The content and format of the materials comprised a general introduction to the materials and the MSCE approach was referred to as *explanations for the teacher*, exemplary lessons for teachers, and student worksheets. The main features of the exemplary lessons included support functions in the areas of lesson preparation, subject matter knowledge, teaching strategies, and learning effects (see Box 6.1).

The results of the study indicated that participant teachers found the overall format of the exemplary lesson materials good and easy to follow. All participating teachers felt that the materials provided clear and adequate information for the preparation of both practical and theory lessons and for classroom implementation of the micro-scale chemistry approach. They mentioned that the materials presented the topic in a simple but effective way, covered content appropriate to the current syllabus, and provided ample opportunities for students to be actively involved in practical work. However, teachers indicated that the materials could be more comprehensive if they included all the 'salts' examined at the national examinations.

Box 6.1 *A summary of the main features of exemplary curriculum materials*

Exemplary curriculum materials for micro-scale chemistry: solubility and precipitation

Explanation for the teacher: provides an overview of the curriculum materials including the topic and its place in the syllabus; the intended grade level; prerequisite knowledge and skills required of students before starting the topic; a brief description of the micro-scale chemistry approach; sequence and content of the lessons; general and specific information on preparation and execution of practical lessons, and on checking student learning.

Preparation aspects of the lesson: materials providing an overview of the whole lesson and intended learning outcomes; a list and specification of apparatus and chemicals (and possible alternatives if not available) required for the experiments; teacher and student activities, and time allocation for the main elements of the lesson; suggestions for trying out experiments beforehand, for possible learning problems (and solutions) students may experience in the lesson, and for setting up the micro-scale lab.

Subject matter and pedagogical content knowledge: the materials provide concise and clear explanations of central chemical concepts (and how to present them) in each experiment. Explanations of chemistry content to a level beyond that suggested for students are included in the teacher notes. Suggestions for possible questions and answers from students are also given.

Teaching strategies: the materials provide a fixed format of experiments and sequence of lesson activities; suggestions for group organization and arrangement of chemicals, tips for conducting discussions; expected experimental results and explanations, safety instructions and clean-up.

Monitoring and assessing student learning: provide suggestions for questions to guide students in data analysis and concept development, as well for homework assignments.

Student worksheet: provides an overview of the purpose of the practical activities; information on materials for the experiments and safety measures, procedures guiding questions for data analysis and interpretation; and follow-up homework assignments. The worksheets are also included in the teacher materials.

Teachers' positive views about the structure of the materials appeared to motivate them to try out the new practical approach with students in their classes. The results suggest that the materials helped teachers to understand the micro-scale chemistry approach and how to implement it. This was already evident during the introductory and preparation workshop, where teachers used the curriculum materials for preparing the practical sessions, discussion, and reflections on the chemistry behind students' experiments. In their reflections, teachers indicated that they found the content of the materials well-structured and the micro-scale experiments clear, simple, and easy to understand and use in the classrooms with students. They further indicated that the materials could also be easily used by a student teacher. However, teachers felt that the materials would even be more helpful to them and their students if they included more practical activities on factors affecting solubility, such as temperature, complex ion formation, and ionic strength of the solution.

Despite the teachers' desire for more content coverage, as stated earlier in this section, the curriculum materials in this study were not meant to provide a full package covering all 'salts' in the A-level chemistry curriculum. The materials were meant to illustrate the use of the MSCE approach in chemistry teaching and to provide effective how to advice to help teachers implement the approach in their classes. Borko and Putnam (1996) state that teacher learning is situated in teacher practice. It was hoped in this study that teachers would use the materials to learn about the new approach as they use it with students in their classes.

Results related to classroom enactment of the approach revealed that both teachers and students felt that micro-scale experimental work was interesting, easy to understand, needed less time, didn't require sophisticated equipment, and could be performed both in the laboratory and in ordinary classrooms. These reactions demonstrated that the approach had potential practicality in the participants' normal conditions. These results suggest also that the use of materials with concrete information about the essential aspects of the micro-scale chemistry lessons helped the teachers to transcend the activation barrier that characterizes the change to an innovative teaching approach (cf. Ottevanger, 2001).

6.2.2 The impact of the MSCE approach on teaching and learning: Overall impression

The impact of the micro-scale chemistry approach on teaching and learning was evaluated by focusing on its actual use in the classroom, teachers' opinions, and students' experiences and learning associated with micro-scale experimental work.

Overall, the results of the evaluation showed that both teachers and students had positive experiences with micro-scale chemistry lesson activities. They both liked doing experiments on a micro-scale and found the approach easy and exciting to use in their classes. The results show that teachers appreciated the exposure to a new, simple, and relatively inexpensive way of organizing student practical work. Likewise, the results show that most students were excited to be involved in the micro-scale chemistry lessons. The overwhelming positive responses of students to micro-scale chemistry lessons in this context could be an indication of the appealing nature of the micro-scale chemistry approach (new, interesting, easy to carry out, fast). On the other hand, it could be an indication of an appreciation of the opportunity to do practical work, because practical lessons are normally not offered in Form 5 chemistry lessons. In this context it is reasonable to expect that students would react positively to any approach which involves them in doing practical work. However, evidence from previous research supports the first perspective (Bradley, 2000; Vermaak, 1997). In his investigation on the impact of micro-science on pre-service and in-service teacher education, Bradley (2000) found that tutors who used micro-scale chemistry kits found practical sessions much easier than before and the students seemed much more interested. Similar positive attitudes toward micro-scale chemistry were also found among South African secondary school students (Vermaak, 1997).

6.2.3 Impact of the MSCE approach on teachers

The impact of the MSCE approach on teacher learning has been demonstrated in various ways related to content and pedagogical support. Results from the reflective interview revealed that participant teachers had positive opinions about their own learning experiences with the micro-scale chemistry approach. Teachers indicated that the MSCE exemplary lesson materials provided them with clear and concrete information about concepts demonstrated through the micro-scale experiments and thereby enhanced their subject matter knowledge of particular topics in the A-level chemistry syllabus. Teachers also indicated that the good structure and adequate content coverage of the subject matter in the materials offered enough support for teaching solubility and precipitation by combining theory with practical activities.

The above findings showed that by interacting with the materials during the introductory workshop teachers enhanced their own chemistry knowledge and pedagogical skills. By preparing all the chemicals, trying out experiments, and reflecting on the results with the help of exemplary lesson materials and interaction with the researcher, teachers indicated that they had gained insights about micro-scale chemistry techniques and how to better organize practical lessons aimed at involving students actively in the learning process. Teachers' personal experiences with micro-scale experiments seemed to increase their confidence and motivation to use the MSCE approach in their classes. Teachers became aware of the potential benefits of micro-scale activities as well as the possible difficulties (and how to deal with them) that may be encountered when using the approach with students.

These results are in agreement with the findings of Grossmann and Thompson (2004) who found that the curriculum materials served as a scaffold for new teacher learning as they provided teachers the opportunity to try out new ideas and teaching strategies in their classes. In this study, teachers felt that they gained some new ideas, such as logical and simple structure of students' experiments and improvisation of apparatus. Teachers indicated that with the micro-scale chemistry approach they also learned how to incorporate pre-laboratory exercises in the practical lessons.

The above results are consistent with the findings of Ottevanger (2001), which showed that teacher support materials help teachers overcome the activation barrier that characterizes the change to an innovative teaching methodology. The findings of the MSCE study have shown that the materials provided teachers with adequate support in their lesson preparation as well as in the lesson implementation. With the support of curriculum materials teachers managed to carry out most of the MSCE activities with students as suggested in the curriculum materials. Results from the summative evaluation showed little variation in performance between the two participant teachers, suggesting that they adhered to the advice provided in the materials. Differences in teacher performance were found for some specific elements of the lessons including the ability to link pre-laboratory exercises to student practical, reflection with students on the procedures and results, and help for students to link observations with appropriate theory. This might be an area where teachers need more support to improve their role as facilitators of learning not only for the MSCE approach but also with other chemistry teaching approaches.

Results from teacher interviews indicated that they needed more time for the introductory workshop to get more insights on the MSCE lesson materials. However, the classroom observation results indicated that participant teachers did quite well in introducing micro-scale lessons in the classes and most of the lesson activities were executed in line with the suggestions given in the curriculum materials. Results showed that because there were few areas of lesson implementation, teachers needed more practice and support in order to facilitate student learning with micro-scale chemistry activities. Helping students link pre-laboratory exercises to practical work, to predict and observe results, and improve the timing of small group discussions and provide the opportunity for presentation of results were some of the aspects of the MSCE approach teachers seemed to need more coaching in. Yet more support would be useful after teachers experienced using the new approach in the classroom. This conclusion supports the observation by Ottevanger (2001) that providing feedback on the lessons during and immediately after classroom observations would be an excellent moment to support teachers in their development.

6.2.4 Impact of the MSCE approach on students

The third question in the summative evaluation phase of the study was: *What do students experience with and learn from the MSCE approach?* The evaluation results indicate that the use of the MSCE approach in chemistry teaching had a positive impact on both affective and cognitive outcomes of students.

Affective learning outcomes

Observed classroom practices, the results of the student questionnaire, and student interview data indicated that students enjoyed doing experiments by themselves and appeared to develop a feeling of working like a chemist as well as increasing confidence in their abilities to do practical work. The majority of students found chemistry classes with MSCE activities more motivating than regular lessons. They appreciated the simple set up of experiments and were fascinated by the results of those experiments. Results related to classroom enactment revealed that students liked the positive climate of the classroom created during the MSCE lessons. They liked the way each member participated actively in the experiments and appreciated the good working relationship among themselves and their teacher. Students indicated that working in small groups increased cooperation and sharing of ideas among themselves and the teacher. They felt that teachers in these lessons were open to questions, and friendly, which gave students the confidence to express their ideas more freely than in regular classes. Students also indicated that the practical experience gained from the micro-scale lessons increased their confidence in carrying out practical work. However, a few students indicated that they did not like sharing one set of chemicals between small groups because some students were not as careful in the use of instruments, and this could become therefore a source of errors in their results.

The above results indicate that students' experiences with the micro-scale chemistry lessons were mostly positive. Criticism and negative opinions were rare, coming from just a few individual students. On the other hand, given such positive results, it can be assumed that integrating micro-scale experiments into teaching would help increase student motivation and interest in chemistry. This assumption is consistent with the views of Hofstein and Lunetta (2004) that the laboratory, as a unique social setting, has (when activities are organized effectively) great potential to enhance social interactions that can contribute positively to developing attitudes and cognitive growth. Similarly, the findings of this study strongly suggest that the use of micro-scale experiments in chemistry teaching have the potential to promote an active classroom learning environment through small group activities. The above results support previous work in micro-scale chemistry (Bradley, 2000; Vermaak, 1997, Towse, 1998) and seem to be consistent with other research which shows that students' participation in practical activities leads not only to greater understanding but also to greater interest in the study of chemistry (Demircioglu, Ayas, & Domircioglu, 2005; Freedman, 1997; Thompson & Soyibo, 2002; Wachanga & Mwangi, 2004).

Cognitive learning outcomes

Students' good performance on the achievement test on solubility and precipitation concepts was considered one of the indicators of the impact of the MSCE approach on cognitive learning outcomes.

The results, based on item analyses of both multiple choice and short-answers measures, showed that students exposed to the MSCE activities performed significantly better than students taught by regular teaching methods on items related to scientific reasoning. Conversely, students who were taught through regular teaching methods performed significantly better than those students exposed to the MSCE practical activities on factual knowledge items.

Learning scientific facts and concepts as well as developing scientific reasoning skills are important goals of science education in general and practical work in particular (Eijkelhof, 2002; Lazarowitz & Tamir, 1994). The impact of different instructional emphases on student learning outcomes, as demonstrated by micro-scale chemistry practical activities and regular teaching methods, suggests a need to balance the application of methods. From the findings it became clear that students who had opportunity for micro-scale chemistry practical experiences demonstrated better reasoning skills as compared to those students who learned solubility and precipitation without practical work. This means that by engaging in micro-scale practical activities students had more opportunities for developing and practicing scientific reasoning skills through activities such as pre-laboratory exercises, data analysis and interpretation, group discussion, and follow-up assignments than for acquiring factual knowledge. Similarly, it appears that involvement in practical activities emphasized process skills and the application of concepts rather than learning chemistry facts. The fact that students in the experimental group were able to apply the concepts they learned by solving problems indicates that the MSCE practical activities contributed to the development of chemistry concepts. This is in line with the questionnaire responses, in which students strongly agreed that exposure to MSCE activities helped them understand the topic of solubility and precipitation and its application in qualitative analysis.

As expected, the study also revealed a big difference in the patterns of interactions between students exposed to the MSCE approach and those students taught by regular classes. Students in MSCE classes participated actively in small group experiments and indirectly initiated dialogue with the teacher through questions, while in the regular classes most of the talk was initiated by their teacher in whole class instructions. It has been argued that allowing students multiple opportunities to articulate their ideas to peers and to hear and discuss others' ideas enhances their learning (Lunetta, 2004). The difference in classroom interaction patterns between experimental and control group may thus have contributed to the differences in student performance on the test between the two groups.

6.3 REFLECTIONS ON THE RESEARCH METHODOLOGY

As outlined in Chapters 1 and 4, and earlier in this chapter, the MSCE study adopted a development research approach. This research approach allows the realization of promising small-scale examples of interventions and generation of methodological guidelines for the design and evaluation of such interventions (van den Akker, 1999). Development research provides flexibility in developing an intervention stage-by-stage within the problem context. This research approach was therefore considered useful and appropriate for Tanzania because of the opportunity for designing an intervention with local relevance. The research approach provided opportunities for better understanding of local implementation conditions and the difficulties teachers might experience in the implementation process, which were important for future improvement of the intervention.

The study employed both qualitative and quantitative methods to allow the researcher to develop an overall picture of the intervention. In the earlier stages of the research, qualitative data collection methods were used, and towards the end of the research both qualitative and quantitative methods were applied. By combining qualitative and quantitative methods, it was possible to explore teacher and student views about the MSCE intervention in-depth. In this section, some reflections on research methodology focusing on the curriculum profile, quality of the student achievement test, and the researcher's role are presented.

6.3.1 Focus of the curriculum profile in the MSCE study

Investigating teacher and student classroom practices with the micro-scale chemistry approach during lesson implementation was considered a necessary condition for determining the effectiveness of the intervention (Millar et al., 1999; van den Akker, 1998). In establishing whether the actual classroom implementation of the MSCE lesson elements matched the intentions of the developer, classroom observations were carried out with the help of a curriculum profile.

In recent years, the curriculum profile as an observation instrument has been used by several studies in contexts similar to the current study (Kitta; 2004; Motswiri, 2004; Ottevanger, 2001; Tilya, 2003). In these studies the curriculum profile has proved to be a useful research tool in establishing the degree of implementation of curriculum innovations by teachers. The focus of the curriculum profile in all these studies has been on teacher activities. When using the curriculum profile, it is easy to follow the activities in-depth by focusing on one person (the teacher), hence providing comprehensive information about teacher performances with regard to the intended change or innovation. However, focusing only on the teacher might characterize the operational curriculum (with innovative ideas) as more teacher-focused with less attention paid to learner behaviour related to the innovation. The latter could also provide useful information about classroom implementation of an intervention.

The curriculum profile as an observation instrument helps paint a picture of how the intentions of materials developers are actually being put into practice (Ottevanger, 2001). In the MSCE study, the curriculum profile was used to explore how both teachers and students were able (or not able) to implement micro-scale chemistry curriculum materials in their classroom contexts. The main emphasis of the profile elements was on the use of the curriculum materials and how the micro-scale approach facilitated interactions between and among students and between students and the teachers. The use of a curriculum profile focused on both teachers' and students' activities provided an opportunity for collecting richer data on what actually happens in the classroom during implementation of the MSCE approach. Richer data on the curriculum in action were seen as particularly helpful in drawing corroboration of findings between interview and questionnaire and in the interpretation of student test data.

Despite the perceived advantages of using the curriculum profile, the researcher also experienced some practical problems in collecting data using this instrument. It was not easy for one observer to use the instrument to capture in detail simultaneous events in small groups, for example, the types of questions students asked each other and the teacher, and the type of responses. Similarly, it was not easy to follow in detail how students in each group shared roles in performing the lesson activities including setting up the micro-scale apparatus, collecting and analyzing data, and drawing conclusions from the experimental results. For effective use of the curriculum profile it would have been helpful to have two observers, one to focus on student activities and the other on the teachers' role in facilitating those activities. An alternative strategy for obtaining richer data via this particular type of curriculum profile would be to select fewer groups to gather observational data about group practices with the proposed intervention and on the role of the teacher in facilitating group learning.

6.3.2 Instrumentation: quality of the student test

The MSCE study used both qualitative and quantitative methods of data collection at the summative evaluation stage of the MSCE intervention. A 15-item test consisting of multiple choice and two short-answer questions was applied to measure students' achievement in chemistry for both students taught with the MSCE approach and those taught through regular methods.

During test development, the researcher considered using relevant questions from past examination papers prepared by the National Examination Council of Tanzania (NECTA) as a viable option to optimize the quality of the test. Such questions are usually validated and therefore would help construct a valid and reliable test. However, there were concerns about using such questions. The researcher was aware of the common practice among A-level students in school and during holidays to study the syllabus topics *in advance* through privately arranged tuition classes (mainly due to lack of confidence that schools would be able to finish the syllabus, shortage of teachers, and the desire to pass national examinations). Much of the teaching-learning styles in those classes focused on solving questions from past examination papers (Sambo, 2001). Such practices encouraged rote learning and students could easily memorize the answers. It was therefore felt that using past examination questions would not provide a realistic picture about the impact of the intervention on student cognitive outcomes. With these concerns the decision was made to construct the test based on the instructional objectives from the syllabus used.

The test items were developed by the researcher and validated through consultations with chemistry content and pedagogy experts as well as chemistry teachers who participated during the formative evaluation of the intervention. The test items were also piloted once with a few A-level chemistry students to further validate the items and establish their practicality. As a result, much attention was paid to every individual item, to syllabus coverage, and whether the test was actually checking what was taught. However, not enough attention was paid beforehand to the reliability of the test. Unfortunately, this was only realized and recognized during data analysis. As a result reliability of the test as whole was very limited. The low reliability of the test made it difficult to use overall test scores to assess the impact of the MSCE approach on student cognitive outcomes. Instead, test scores were analyzed out at item level. Student performance on individual items provided positive results attributable to the intervention. In this way it was possible to compare and contrast student results from the experimental and control group. Yet, as the study showed, the test results should be interpreted carefully.

6.3.3 Researchers' multiple roles: Maintaining balance and minimizing conflicts

At the beginning of this section, it was stated that a development research approach was adopted for the MSCE study. One of the benefits of this approach was that it stimulated the researcher to learn and perform a number of (new) roles including designer-developer, facilitator, and evaluator-researcher. In the development of exemplary curriculum materials the researcher was the designer, in the introductory workshop he took the role of facilitator, and in the classroom he was a researcher (observer). As a designer the researcher aimed at developing high quality materials, as facilitator at ensuring that teachers were adequately introduced to the intervention, and as a researcher at being objective. These roles were essential in order to develop and evaluate the intervention (the micro-scale chemistry practical approach). Playing multiple roles was sometimes beneficial but also created problems in the research process. An example of such problem was the tension over the dual roles of the researcher-facilitator during classroom observations. Teachers as well as students often asked for clarification of some aspects of the lesson activities and the researcher needed to maintain his role as researcher. From the classroom observations we learned that teachers needed more support or coaching during classroom implementation of the new approach. This suggests that the use of an external evaluator would be a better strategy for an objective assessment of classroom practices with the new approach.
However, being a designer of the exemplary MSCE curriculum materials and an observer of how teachers and students were implementing the new approach in their classes could have positively influenced participant teachers' classroom performance due to 'the Hawthorne effect' (Krathwohl (1998). Krathwohl cautions that people tend to increase their effort and motivation when being watched or evaluated while implementing a new system aiming at improving their performance, even if the new method is no better than the old way of doing things.

Combining these roles, the researcher could have also made an overly positive interpretation of data gathered from questionnaires and interviews. To address these dilemmas, van den Akker (2002) suggests the use of multiple methods and sources of data collection as well as discussions with all parties involved in the development for deeper understanding, stronger commitment, and for reaching careful and balanced conclusions. To reduce the possible bias of the results, the present study employed triangulation of methods (observation, interview, questionnaire, and achievement test) and sources of data collection (Cohen, Manion & Morrison, 2000; Krathwohl, 1998).

6.4 CONCLUSIONS

One of the lessons learned from the literature is that exposing teachers to new ideas, resources, and opportunities broadens their awareness of possibilities for change and fosters a sense that alternatives are possible (van den Akker, 1998). The MSCE study was undertaken to explore the possible use of simple forms of practical work in order to support an active learning environment based on low equipment and consumable demand, the ultimate goal being to improve the chemistry curriculum for secondary education in Tanzania. In particular, the study was set up to design and evaluate a micro-scale chemistry scenario with exemplary curriculum materials as the support structure that could assist teachers with the implementation of more practical work in A-level chemistry classes. The following conclusions can be drawn from the findings of this study.

The study has shown that the MSCE approach, introduced via carefully designed and validated curriculum materials, has the potential to change the way chemistry is taught and learned in A-level classes in Tanzania. The study has revealed that micro-scale experiments developed in this study with exemplary lesson materials, containing adequate procedural specifications, are feasible for use in A-level chemistry classes and are effective in providing positive learning experiences for students. Evidence from the summative evaluation shows that the MSCE approach is not only easy to use but also makes chemistry classes more interactive, interesting, and enjoyable, allowing students to carry out experiments for themselves, collaborate with peers, and communicate with their teachers freely. Besides the affective outcomes, the findings suggest that students develop better reasoning skills by engaging in micro-scale (hands-on/minds-on) activities.

Furthermore, the study concludes that:

- The use of curriculum materials as a vehicle greatly helps teachers implement the MSCE approach in their classrooms. Procedural specifications on critical aspects of the curriculum enable teachers to work with and learn about the MSCE approach without an extensive initial orientation.
- A properly designed worksheet with concise and clear information about the practical (laboratory) provides enough structure and support for groups of students to carry out micro-scale experiments without the constant intervention of the teacher.
- The positive results show that the micro-scale approach can be successful in facilitating implementation of practical work in resource constrained classes. This is because the MSCE approach employs small amounts of chemicals and cheap apparatus, and hence is affordable to most schools, and some of the required materials, e.g., plastic sheets and pipettes, are locally available.
- Teachers' role in monitoring student learning progress is essential for ensuring success in the implementation of the micro-scale chemistry practical work. Although participant teachers implemented the MSCE approach relatively successfully in introducing pre-laboratory exercises, group organization, and guiding students through the practical activities, they had great difficulty in keeping time for small group discussion. This resulted in less time for groups to present their ideas to the whole class and receive feedback from classmates and teacher.

The major result of this study has been to introduce promising ways to motivate the teaching of chemistry in A-level chemistry classes in Tanzania. Overall, it can be concluded that the MSCE approach is a powerful method to change teaching and learning practices in chemistry classrooms. The materials need only short introduction, are easy to use, engage learners actively in the learning process, foster positive classroom interactions, promote positive student attitudes toward chemistry, and provide more opportunities for developing thinking skills.

6.5 RECOMMENDATIONS

The MSCE study is among the first few pioneer studies (cf. Kitta, 2004; Tilya, 2003) in science education based on development research approaches and aimed at improving science and mathematics teaching in Tanzanian secondary schools. The study tried out and evaluated prototypes of micro-scale chemistry curriculum materials for teaching solubility and precipitation topic in A-level secondary schools. The findings from this study are significant for the Tanzanian context, especially for improving chemistry education in secondary schools. Based on the findings the following recommendations are made.

6.5.1 Recommendations for policy and practice

The findings of this study have indicated that the MSCE approach has great potential for improving the teaching quality and learning practices in A-level chemistry classes in Tanzania. Participant teachers highly appreciated the micro-scale chemistry experience as a promising solution to the problems they faced in organizing student practical work. Likewise, students seemed highly motivated and interested in learning chemistry with micro-scale experimental work.

Despite the positive impact of the micro-scale chemistry approach on teachers and students there are basic considerations, which if not carefully taken into account could limit implementation of the approach. These include the established curriculum, the examination system, and initial costs for micro-scale equipment (Bradley, 2001).

- *Curriculum*: One of the challenges of the current A-level chemistry curriculum is a lack of guidance about what practical work constitutes and when to do it, other than for the purposes of final examination preparation. The Tanzania Institute of Education (TIE) should consider this challenge and take the lead in developing a practical manual for A-level students that will serve as a clear and concrete guide for teachers in implementing practical work. In view of the outcomes of this study and the observed trend toward practical work using simple equipment in science curricula in many sub-Saharan African countries, the Ministry of Education and Culture should consider incorporating the MSCE approach in current and future curriculum reform initiatives under the Secondary Education Development Plan (SEDP).
- *Examination system*: Aligning assessment practices with the processes of learning and teaching is essential for improving classroom practices. At present, examinations are not quite aligned with the micro-scale approach developed in this study. The Ministry of Education through NECTA should consider revising the format and blueprint of practical chemistry national examinations so that it also aligns with the MSCE approach by including a larger variety of questions which test students in both lower and higher order thinking skills, and also affective and psychomotor skills. It could also institute a monitoring procedure to ensure that schools do practical work regularly and build in a regulation on the standards of practical work required for a school to qualify for practical examination. In this way the assessment system at national level is likely to

promote curriculum reforms in the classroom. Inclusion of both lower and higher level student cognitive abilities will motivate teachers to focus their teaching on a wide range of cognitive levels instead of emphasizing simple memorization of facts.

- *Initial cost of the micro-scale equipment*: Although the initial investments are limited for implementing the MSCE approach, they are well below the more established chemistry practical work approaches; the government should still meet the cost of chemicals and equipment.

6.5.2 Recommendation for teacher education institutes and in-service providers

It has been emphasized that although many factors influence the nature of learning in student practical work, the single most important is the teacher (Bradley, 2000; Lazarowitz & Tamir, 1994). Practical work, including micro-scale chemistry activities, will not result in concept learning by students unless the teacher is able to help this process to happen (Bradley, 2000). Based on the results of this study, to effectively support student learning, teachers need to be transformed by personally experiencing the micro-scale chemistry experimentation approach in the context of their chemistry learning. One promising strategy by which teachers can be introduced to and practice to use micro-scale chemistry activities is through *pre-service teacher education programmes*. These could be conducted as part of a science education methods course; when they learn how to design lesson materials for classroom teaching, they could do micro lessons and also practice these skills in their teaching practice training. In this way, the MSCE curriculum materials could be used as learning resources as an example of a promising strategy for practical work in a low resource environment.

As revealed from the results of this study, participant teachers were very enthusiastic about learning the micro-scale chemistry approach, particularly as it involves students actively in the learning process. However, the study involved only five teachers, who also did not participate in its development. One way experienced practicing teachers can successfully implement such a new promising teaching strategy in their classrooms is to experience such learning environments themselves (Borko & Putnam, 1996). A good learning experience for in-service teachers in this case would be first to use the MSCE exemplary curriculum materials to practice the approach, and second to use them as tested examples to develop (guided by experts) lesson materials for additional selected topic/ concepts from the syllabus. Material development workshops organized in-service would be an appropriate avenue for realizing the MSCE ideas, where university based science education researchers meet with chemistry teachers and develop the materials together. It is therefore recommended that TIE in collaboration with NECTA, chemistry teacher educators, and teachers together should pioneer the development of a practical manual for A-level chemistry students (with teacher support materials) incorporating the MSCE design ideas. This is one way to improve the effective implementation of chemistry curriculum for A-level secondary schools in Tanzania.

6.5.3 Recommendation for future research

Practical (laboratory) activities in science teaching can enable collaborative social relationships as well as positive attitudes toward science and cognitive growth (Lazarowitz & Tamir, 1994; Lunetta, 1998). However, it has also been observed that little attention is given to promoting and examining collaboration and reflective social discourse in school science laboratory classrooms (Hofstein & Lunetta 2003). The current study has produced promising initial results about the potential of micro-scale chemistry practical work to engage students in small-group discussions and foster positive attitudes toward chemistry and chemistry learning in A-level classrooms in Tanzania. However, the study has also generated some questions for group work, which are important for improving classroom practices with micro-scale approach for student learning. In order to determine the impact of the approach on group learning, it would be worth investigating further, first, what exactly takes place during small group discussions. Second, what are the types and cognitive levels of the focus questions that should be asked to guide students' discussion in order to foster conceptual development and scientific reasoning skills? Third, what support is necessary for teachers to successfully manage and facilitate group learning with micro-scale chemistry activities? Fourth, how can science teachers be motivated to do practical work regularly and ensure that their students have experienced practically most of the contents prescribed in the advanced level curriculum? This includes policies on school and systemic based motivation, such as monitoring, rewards, and conditions that make it feasible for teachers to do practical work regularly. Investigating these questions offers possibilities for enriching the MSCE approach and improving the implementation of the school science curriculum.

One of the important challenges regarding the implementation of laboratory (practical) work in science education is to develop an appropriate means (assessment tools) of measuring student achievement in such a unique leaning environment (Hofstein, 2004). As reflected in this study, the use of paper-and-pencil test appears to be a limited tool in assessing a wide range of learning outcomes associated with laboratory experiences or practical work. To explore the full potential of the impact of the MSCE approach on student achievement, more enriched forms of assessment strategies (a combination of valid and reliable tests, performance based and observational assessments) need to be developed and implemented to measure all possible learning outcomes of laboratory work in all the three domains of learning. Such instruments will also help teachers and researchers identify what exactly students are learning both in terms of concepts as well as procedures. Therefore, development and implementation of assessment tools is another important area for further work in enriching the micro-scale chemistry method and for improving practically-oriented chemistry teaching in Tanzanian secondary schools (cf. van den Berg & Giddings, 1992; Nakhleh, Polles, & Malina, 2002).

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ENGLISH SUMMARY

Micro-scale experimentation as a catalyst for improving the chemistry curriculum in Tanzania

BACKGROUND

Quality science and technology education play an important role in the social and economic development of any country. It is through quality education that nations obtain skilled human resource to serve in various sectors of the nations' economy. Realizing the importance of science and technology to development, Tanzania, like other countries in sub-Saharan Africa, has been trying to invest on and improve science and mathematics education as part of the reform efforts of its education sector, initiated in the mid 1990s. Among the priorities of the reforms has been on improving science education provision in secondary schools. One of the emphases in the school curriculum is the use of learner-centred teaching methods, which provide opportunities for students to participate actively in the teaching-learning processes and promote learning with understanding.

Against the above emphasis, however, the reality in many schools in Tanzania is that science teaching is based on transmission of information through exposition, where teachers dominate the large part of the teaching-learning processes (Chonjo, et al., 1996, 2001; Galabawa, 2000; Knamiller, et al., 1995, Osaki, 1999). The different roles that teachers and students play in the teaching and learning processes do not focus on/ promote active student participation. Students largely carry out the passive roles, such as note taking, listening and watching. Patterns of classroom interaction, such as student-teacher interaction, student-student interaction and student-material interaction are greatly constrained by several factors such as shortage of appropriate textbooks, equipment and chemicals; large class sizes, overloaded syllabi and examination demands. Observed classroom practices reveal also that teachers' pedagogical skills are weak, most teachers have inadequate practical skills or lack competence, and continue to lecture, with a focus on the next examinations rather than promoting understanding. Other obstacles that have been identified to hinder effective science teaching in schools include work overload for teachers (due to shortage of teachers) and content overload in the syllabus, and coupled with teachers' behaviour to teach in rush in order to meet examination requirements. The current practice of ranking schools according to examination performance by the NECTA worsens the situation, as most schools' main goal is to come top in examination performance.

With regard to provision of practical work, particularly in chemistry teaching, observed classroom practices indicate that most students do not do enough practical work (Chonjo et al., 1996, Mafumiko 1998, Mshashu, 2000). Practical work is offered mainly to the final year students (Form 4 & Form 6) aiming at preparing them for the (external) national practical examinations. Many reasons have been given for the observed practices. These include lack of laboratory facilities, lack of expertise and confidence among teachers, lack of technician, lack of time due the pressure to complete the long syllabus to meet examination requirements, and increased class sizes. For A-level chemistry in particular, apart from shortage of textbooks, earlier studies show that there has been a lack of laboratory manuals for practical work, lack of a systematic INSET programme for A-level teachers on developing practical skills.

In view of the above situation the Tanzania government in collaboration with development partners has been making efforts to improve the practice of science teaching and learning in the country. Examples of such efforts include employing more science and mathematics teachers, supplying of science apparatus to a number of new schools, development of in-service education materials for schools (Osaki et al., 2002). However, only few of these efforts focus on research into the development of teaching and learning materials (including alternatives to expensive laboratory practical work) and trying it in real user settings (i.e., with teachers and students in the classroom). Considering the costs of resources for practical work and limited knowledge and skills of teachers, the present study focused on exploring the use of micro-scale chemistry with exemplary curriculum materials as a promising strategy for supporting teachers in implementing practical work in A-level chemistry teaching in Tanzania.

AIM OF THE STUDY

The MSCE study intended to explore, design and evaluate a small-scale; low-cost teaching approach that could contribute to the implementation of practical work in chemistry teaching in Tanzania schools. In view of constraints of resources, infrastructure, time and overloaded syllabuses, the study set out to introduce micro-scale (hands-on/ minds-on) activities as a means to perform practical work in A-level chemistry classes without the need for well-equipped laboratories. Such activities also aimed at providing opportunities for students to engage in a process of active learning away from the usual 'passive roles' of note taking, listening and watching. In designing and evaluating the micro-scale chemistry practical approach, the study considered exemplary curriculum materials as an appropriate vehicle for introducing and translating the micro-scale experimentation into classroom practice. To develop such materials the study was guided by the following research question.

> *What are the characteristics of micro-scale chemistry materials that contribute to the initial implementation of practical work in chemistry education in Tanzanian secondary schools?*

RESEARCH APPROACH AND DESIGN

The study adopted a development research approach to answer the research question. Apart from generating information that provides useful solutions for a variety of design and development problems in sometimes complex situations (van den Akker, 1999); development research approach allows step-by-step development of an intervention within the problem context. This research approach was therefore considered useful and appropriate for the study because of the opportunity for designing an intervention with local relevance.

The overall design of the study comprised of three stages. The first stage, front-end analysis, included a context analysis and a literature review. The context analysis sought to gain insights into the situation of teaching and learning science in Tanzanian secondary schools with particular attention to implementation problems of chemistry practical work. The literature review aimed at gaining insights into the intentions, current practices and effectiveness of practical work in science education at international, regional and local levels. The main focus of the review was on gaining insights into micro-scale chemistry as a promising example of low-cost methods for promoting practical work in secondary chemistry teaching. The second stage involved development of prototypes of exemplary curriculum materials. In this stage, a succession of prototypes was developed through the cyclic approach of design, development and formative evaluation activities. The formative evaluation (carried via expert appraisals and classroom try-outs) aimed at increasing the quality of prototypes. In the formative evaluation of the first version emphasis was on obtaining indications for improvement of validity and practicality of the intervention. In the formative evaluation of the subsequent prototypes the emphasis shifted to practicality and effectiveness of the MSCE approach. The final version of the MSCE curriculum materials was field tested and evaluated. In this stage the study focused on the effectiveness of the intervention as measured through teachers' opinions about the approach, actual use of the approach in the classroom, students' experiences and learning outcome. In this stage, a quasi experimental research approach was used to compare the impact of micro-scale exemplary curriculum materials on student learning of a specific syllabus topic to the normal instructional approach teachers normally use in teaching the topic. The main results of the evaluation are summarized in the next sections.

RESULTS

The effectiveness of the MSCE approach was measured by the classroom practices of teachers and students, participants' self reports, student learning experiences and outcomes. The summative evaluation resulted into the following main findings.

Teacher opinions about the of micro-scale chemistry approach

Teachers' reactions to the MSCE approach focused on the relevance, structure, presentation of the exemplary lesson materials; and usability of the micro-scale experiments in their classroom settings.

In general, teachers' opinions about the approach were positive. Teachers felt that the materials and the MSCE approach, were very clear, appropriate for the level of students, and presented the experiments and content in a simple and logical sequence, which made it easy to follow and understand. Following personal experiences with micro-scale experimentation in the introductory workshop, teachers felt that their scope of practical work had been increased. They found that the new approach provided them with the possibility to do practical work even with large number of students using minimum resources. Teachers also indicated that through exposure to the new approach their subject matter knowledge and teaching skills regarding solubility and precipitation had been enhanced. Furthermore, teachers' opinions indicated that micro-scale practical activities were very helpful in engaging students actively in the learning process, stimulating interest in chemistry lessons and practical work in particular.

Classroom observations indicated that participant teachers managed to implement most of the lesson activities in their classroom settings according to advice provided in the curriculum materials. Nevertheless, the observational data indicated that teachers had challenges with supervision / facilitation of small group activities due to the active participation of students. In most groups discussions took longer time than was suggested. Similarly, participant teachers of the two experimental schools appeared to prefer discussing with students in small groups rather than allowing groups to present their findings and discuss as a whole class.

Student learning experiences and outcomes

Student learning experiences and outcomes were judged based on the students' perceptions and opinions about learning chemistry with micro-scale chemistry practical activities and on the achievement test results of both the experimental and control students.

In general, the outcomes indicated that student experiences with chemistry lessons conducted with micro-scale experimental work were positive. Most students appeared to like practical lessons conducted with the micro-scale approach. They found it easy to understand and carry out many experiments in a short time; it engages them actively in both doing and thinking, makes chemistry lessons more interesting and enhances their understanding of the subject matter. By doing experiments themselves, students felt that their confidence in practical work had been increased. They also indicated that the experiments and follow-up questions provided them a very stimulating environment to think critically and prepare about the lesson topic. These results suggest that the micro-scale chemistry approach when carefully integrated in chemistry teaching can be used as vehicle to promote student positive attitudes toward chemistry and improve cognitive outcomes.

Classroom observations revealed that students liked the active learning environment that was created during the MSCE lessons. They appreciated the way the learning activities engaged them actively in the learning process and the positive interaction among themselves and the teacher. Students felt that working in small groups increased cooperation and sharing of ideas among peers and freedom to express their thoughts to classmates and to the teacher. They felt that teachers in these lessons were open to questions and friendly, which increased their confidence to express their ideas more freely than in their regular classes.

Nevertheless, a few students felt that the pre-lab questions were too many and cognitively challenging to be completed within the practical sessions. Also a few students expressed concerns on the possibility of contamination between different reagents due to small boxes on the reaction grids These findings suggest that although the approach appears to be effective in promoting student active learning and interest in chemistry, the number and difficulty level of pre-lab questions; and reagents per sheet might need a review to avoid contamination as well as cognitive overload of students.

With respect to the student achievement test, item analyses revealed that there was significant learning gains in favour of the experimental group on items relating to student reasoning abilities. On the other hand, the analyses revealed that students of the control group had significant learning gains on factual knowledge items.

CONCLUSIONS

The purpose of the study was to design and evaluate an intervention that could help secondary school teachers in Tanzania implement practical work to promote active learning environment in A-level chemistry classes with low demand on equipment and chemicals. In particular, the study intended to determine the characteristics of micro-scale chemistry exemplary curriculum materials as the support structure that could successfully assist teachers with implementation of more practical work in A-level chemistry teaching in Tanzania. The study employed a developmental research approach in which exemplary materials were developed, and the prototype so developed was tried out with a small sample of teachers in selected schools in two regions, followed formative and summative evaluation. The following conclusions are drawn from the findings of the study.

The findings of the study indicate that a micro-scale chemistry instructional scenario with exemplary curriculum materials as the support structure has the potential for improving teaching and learning practices in A-level chemistry classes in Tanzania. The findings suggest that the micro-scale chemistry curriculum materials developed with procedural specifications are feasible for use in A-level chemistry classes and are effective in providing positive learning experiences for students. Apart from making chemistry lessons more interactive, interesting, and enjoyable for students, the findings suggest that micro-scale chemistry approach helps students develop better reasoning skills by providing them more opportunities for practical experiences, discussion and reflections about the phenomena they observe among themselves, and with the teacher. It is recommended that further work be carried out with the micro-scale teaching approach so that it can be spread to more schools.

APPENDIX A1

Teacher evaluation questionnaire (try-out)

School ---Date -------------------------Class taught---------------

Lessons taught---

Your position --

Academic qualification ---

Teaching experience at this school (years)---In this subject-

---

PLEASE use a separate sheet of paper for questions 3-9 and attach your answers to this form

1. Please describe your general impression on these lesson materials:
   Relevance :
   Content:
   Structure:
   Presentation :

2. What did you like and dislike about this materials

Like most	Reason
Dislike	Reason

3. What things would you like to have taken out of this lesson?

4. What things would you like to have added to this lesson?

5. How will you organize the timing of this lesson?

6. What do you think about doing these experiments in normal classrooms? What problems do you foresee?
7. Do you anticipate any particular safety concerns in this activity? If so what ?

8. Will you be able to get all the equipment for the experiments in these lessons?
   a. If not, what will you do?
   b. What specific equipment or materials will be difficult to obtain and why?

9 Do you have any comments or suggestions on these lesson materials?

APPENDIX A2
Follow-up interview with teachers (try-out)

1. What general comment can you make about using the materials in class with micro-scale chemistry approach?

2. Was the lesson material useful during the preparation of this lesson?

3. What things would like to see in the lesson materials and they are missing?

4. How was the participation of the students in these lessons?

5. Do you think students liked the approach? Why or why not?

6. Were there any specific problems in using this approach from the students?

APPENDIX A3
Student questionnaire (try-out)

Dear student,
We would like to know what you think about the MSCE lesson activities which you participated in the last two weeks. There are no right or wrong answers. Your personal opinion is what is required. *Please do not discuss your views with someone else while answering this questionnaire. Be assured that your answers to the questions below will be treated confidentially*

Personal information

0. School--------------------------Date ------------------ Form / Class------------ Your age --------

1. Please list two things you liked about the lessons you did:

   a)--

   Reason ---

   b) ---

   Reason ---

2. Please list two things you disliked about the lessons you did:

   a) ---

   Reason---

   b) ---

   Reason---

3. How were the activities in these lessons different from your regular chemistry classes?

4. Please show by filling the table below how you liked or disliked the activities from the lessons and explain why it was your favourite.

The activities I Liked very much	**Explanation**
The activities I did not like	

5. Please write any other comments or suggestions you may have concerning these lessons on the back of this paper.

APPENDIX A4
Student interview schedule (try-out)

1. Of the activities you did last two weeks, which was your favourites and why?
2. Which do you think helps you to understand better: learning the theory before doing a practical, or doing a practical and then following- up with the theory?
3. How have the lessons you did the last two weeks been different from your normal classes, if at all?
4. How do you feel about practical work, in terms who actually does the experiments?
5. Do you think that the whole class understood these lessons, or do you think that there was some confusion and if so where?
6. If you could have more of anything in your chemistry classes, what would that be?
7. If you could have less of anything in your chemistry classes, what would that be ?
8. Can you think of anything new that you learned from these chemistry lessons?
9. Do you feel comfortable asking your teacher for extra help? Why, why not?
10. Do you have any comments; suggestions or other things you would like to say which you think might be useful?

APPENDIX B1

Curriculum profile

Background information

Teachers' name-------------------------------------, Class-------------- -----------------
Observers' name------------------------------duration of the lesson-------------, Date------

How to use this observation guide: Please mark (**+**) in column 'A' to indicate that the activity was observed, (**-**) in column 'B' to indicate that the activity was not observed at all and plus / minus (±) in column 'C' to indicate that the activity was partially observed/executed.

Curriculum statement items **(**Statement about the event at- each stage of the lesson)	**(+)** **A**	**(-)** **B**	**(±)** **C**
INTRODUCTION TO LESSON			
1. Teacher relates lesson to previous learning/future activities (e.g. checking homework)*			
2. Teacher groups students for pre-lab and experimental work*			
3. Teacher introduces the lesson by an activity' (e.g. pre-lab exercises)*			
4. Teachers makes connection between pre-lab exercise and current lesson activities (if applicable)			
5. Teacher explains clearly the purpose of student practical			
6. Teacher explains how students will obtain materials/ equipment and how they are to be organized			
7. Teacher emphasizes students to read carefully safety instructions before engaging in any experiment			
8. Teacher asks group members to assign and share roles during activities (e.g. chairperson, secretary)			
BODY OF THE LESSON			
1. Teacher explains how to use materials and equipment			
2. Teacher demonstrates experiments to students *			
3. Students actively participate in doing experiment (s)/ hands-on activities*			
4. Teacher moves around groups to ensure experimental set-up and safety			
5. Students use information from the worksheet			
6. Students demonstrate ability in working with apparatus and materials			
7. Students work cooperatively in small groups*			
8. Teacher circulates among students groups asking/answering questions			
9. Students seek help from the teacher during activities*			

Curriculum statement items (Statement about <u>the event</u> at- each stage of the lesson)	**(+) A**	**(-) B**	**(±) C**
10. Students discuss their experimental work/activities in the small groups*			
11. Students show interest in the experiments they are doing			
12. Groups present observations to the whole class			
13. Teacher and the Students discuss the activities as a whole class*			
14. Teacher makes short presentation at different times during activities to help students grasp major concepts			
15. Teacher effectively manages timing of different learning activities*			
CONCLUSION OF LESSON			
1. Teacher, together with draws conclusions from the activity/ experiment*			
2. Teacher discusses with the students their procedures and results			
3. Teacher guides students to understand differences in their results			
4. Teacher helps students to relate the activity with theory*			
5. Teacher summarizes the main concepts learned from the activities*			
6. Teacher checks learning of students (e.g. by oral questions, class discussions , homework questions) *			

General observations

1. Number of students in class [|]

2. Number of small groups [|]

3. Average number of members in a group [|]

4. Was time allocated to different activities or experiments adequate? Please explain. [Yes | No]

5. Type of question asked [Low level | High level]

   Give examples of questions asked.

6. How does the teacher respond to questions? [Negatively | Positively]

   Give examples of the questions asked and their responses.

7. What is the classroom layout (seating plan) Please explain and provide sketch of seating arrangement, e.g. desks arranged in rows, fixed laboratory benches arranged to allow group work, flexible seating arrangement of tables or desks etc.

8. Please provide description of the physical environment of the classroom. Check for posters, models, charts, broken windows, water taps, gas system, Rubbish bins, wall charts, how equipped is the laboratory before MSCE materials? How many students can the laboratory accommodate?

9. Provide summary of learners response to the learning activities

APPENDIX B2

Teacher reflective interview scheme (field-test)

1 What is your general impression of the one-day Micro-Scale Chemistry Experiments (MSCE) briefing workshop?

1.1 How has the workshop helped you with the implementation of (MSCE) lessons in your class?
1.2 What are the important ideas you gained from the workshop experience? Do you have any new skills that improved your abilities to help students learn chemistry? Would you describe those skills please?

2 How has micro-scale experiments helped you to do practical work with large classes/ without the usual practical equipment available?

2.1 How did you ensure active participation when students were working in small groups?
2.2 Assume that Micro-Scale Chemistry practical approach was implemented in the school chemistry curriculum what benefits and difficulties can you foresee?
2.3 What difficulties did you experience in introducing Micro-Scale Chemistry approach in your classroom? (e.g. consider about resources? Students' basic skills? Time management, etc?

3 How has MSCE helped: you to teach about solubility and precipitation; and students to learn about these and Ksp.

3.1 What do you think about group work? Was it successful in your classroom, why and why not?
3.2 In your own opinion how should students seat in the classroom for successful group work?
3.3 Reflecting on the lessons and how you implemented them in your classroom, what are your views on student learning? With your experience with students, what difficulties do you perceive students had with the lessons? Do you think students like the worksheets?
3.4 Recalling how students were doing the activities, what kind of things do you think students benefited /did not benefit?

4 What are/would you be doing different now from what you were doing before the introduction of Micro-Scale approach to experiments?

APPENDIX B3

Student pre- and post-tests on Solubility and Precipitation Test (USPT)

Name------------------------------------ School-----------------------------date------------------- Class---------

Time Allocated: 1 ½ hours
<u>INSTRUCTIONS</u>: Choose the CORRECT answer and mark with a tick (√) against the letter of the answer for question items 1- 13. Use the space provided under each question to write answers for questions 14 and 15.

1. If powder soap (for example, Foma) is mixed with water a soap solution is obtained. Which process below correctly summarises this situation?
a. Solution
b. Dissolution
c. Precipitation
d. Solubility

2. A solute is most likely to be highly soluble in a solvent if:
a. the solute is ionic or polar and the solvent is non-polar
b. the solute is ionic or polar and the solvent is polar
c. the solute is non-polar and the solvent is polar
d. the solute is non-polar and the solvent is ionic

3. Water can dissolve solid ionic compounds at a certain temperature. Which of the following equations best represents the dissolving of NaCl in water?
a. $NaCl(s) \longrightarrow Na^{+}(aq) + Cl^{-}(aq)$
b. $NaCl(s) \longrightarrow Na(aq) + Cl(aq)$
c. $NaCl(s) \longrightarrow Na^{+} + Cl^{-}$
d. $NaCl(s) \longrightarrow NaCl + H_2O$

4. One of the following chemical concept / term describes the normal maximum quantity for solute in a solvent (expressed in---grams/100grams of water) at a certain temperature.
a. Solubility
b. Solute
c. Solvent
d. Concentration

5. Combining aqueous solutions of $BaCl_2$ and Na_2SO_4 gives a white precipitate of $BaSO_4$. Which ion(s) do not take part in the reaction?
a. Ba^{2+} only
b. Ba^{2+} and SO_4^{2-}
c. Na^+ only
d. $Na^+$and Cl^-

Use the information given in table 4.1 (see attached sheet of paper) to answer questions 6-9.

6. Which one of the following compounds would be insoluble in water at room temperature?
a. NaI
b. Ba $(OH)_2$
c. $MgCO_3$
d. NH_4Cl

7. A solution, which contains only <u>one</u> of the following cations: Mg^{2+}, Pb^{2+}, or NH_4^+ is tested with the following reagents and the following results are obtained:

Reagent	Results
0.1 M Na_2SO_4	Precipitate
0.1 M NaI	precipitate
0.1 M $NaNO_3$	no precipitate

This cation is:
a. NH_4^+
b. Pb^{2+}
c. Mg^{2+}
d. Na^+

8. We want to separate the cations in an aqueous solution containing $Pb(NO_3)_2$ and $Ba(NO_3)_2$ by selective precipitation method. Preliminary tests give the results in Table1

Table 1: Selective precipitation of barium and lead ions

	Test solution (anion)			
Cation	NaCl (Cl^-)	Na_2SO_4 (SO_4^{2-})	NaOH (OH^-)	Na_2CO_3 (CO_3^{2-})
Pb^{2+}	White precipitate	White precipitate	Precipitate	Precipitate
Ba^{2+}	No reaction	No reaction	No reaction	Precipitate

Which of the four test solutions in table1 give some unexpected results?
a. NaCl
b. Na_2CO_3
c. NaOH
d. Na_2SO_4

9. When potassium iodide reagent is added to a neutral unknown solution a yellow precipitate forms immediately. What might the unknown solution be?
a. Silver (I) nitrate
b. Iron (III) nitrate
c. Lead (II) nitrate
d. Barium (II) nitrate

10. The correct Ksp expression for CaF_2 dissolving in water is?
   a. $K_{sp} = [Ca^{2+}]^2 \times [2F^-]$
   b. $K_{sp} = [Ca^{2+}] \times [2F^-]^2$
   c. $K_{sp} = [Ca^{2+}] \times [F^-]$
   d. $K_{sp} = [Ca^{2+}] \times [F^-]^2$

11. Which of the following arrangements of the solubility of $CaSO_4$, Ca $(OH)_2$, and CaF_2 is correct?
   a. $CaSO_4 > Ca(OH)_2 > CaF_2$
   b. $CaF_2 > Ca(OH)_2 > CaSO_4$
   c. $CaSO_4 > CaF_2 > Ca(OH)_2$
   d. $Ca(OH)_2 > CaF_2 > CaSO_4$

Salt	**Ksp**
CaF_2	1.5×10^{-11}
$CaSO_4$	7.1×10^{-5}
$Ca(OH)_2$	4.7×10^{-6}

12. What must the silver-ion concentration (in moles/ litre) be in order for precipitation to just begin when 2 ml of silver ion is added to 2 ml of 5.0×10^{-4} M Na_2CO_3 solution? (K_{sp} = for Ag_2CO_3 is 8.5×10^{-12})
   a. 4.1×10^{-9}
   b. 1.6×10^{-8}
   c. 6.4×10^{-5}
   d. 1.3×10^{-4}

13. Two solutions of equal volumes are mixed one containing Ag^+ and the other Cl^-. If at the instant of mixing, $[Ag^+]$ is 10^{-3} M and $[Cl^-]$ is 10^{-3} M, which one of the following statements is true? (Ksp for AgCl is 1.8×10^{-13})
   a. A precipitate forms because Q is less than Ksp.
   b. A precipitate forms because Q is greater than Ksp.
   c. No precipitate forms because Q is equal to Ksp.
   d. No precipitate forms because Q is greater than Ksp

   NOTE: Q stands for ion product and K_{sp} stands solubility product constant.

14. A solution contains Ag^+, Ba^{2+}, Fe^{3+} and K^+. What compounds (give correct formula for each compound) could be added, and in what order, to separate these ions from the mixture. What ion will remain in the solution at the end of the separation process?

Use this space to write answers for question 14.

What compound could be added?	Represent what you would see happening by a net chemical equation.
1st	
2nd	
3rd	
4th	

Explain why would you follow the order of addition from 1st to 4th in order to separate the four ions from a mixture? (*Use the space below to write your explanation*).

15. (a) What is the difference between solubility product and ion product?
    (b) Barium sulphate, which is opaque to X-rays, is used for the "barium meal" to enable X-ray pictures to be taken of the gut. Barium ions are very toxic; why is this not a problem here?
    (c) Will the solubility of Barium sulphate in a solution of 0.25 M Na_2SO_4 be greater or lower than that in pure water? Explain. [*Use the backspace to write answers for this question*]

APPENDIX B4
Scoring scheme for USPT

Answers to multiple choice items
1b, 2 b, 3a, 4a, 5d, 6c, 7b, 8d, 9c, 10d, 11a, 12d, and 13 b.
(1 point awarded for each question to make a total of **13 points**)

Scoring
If the student chooses the correct option (answer) s/he gets 1 point for each question. If the student makes a wrong option (answer) or do not answer the question she/ he gets 0 point.

Answers to short-answer items

14. Answers will vary with respect to which reagent should be added to selectively precipitate one cation at a time, but the order in which the compounds are added and the representation of each reaction by a net chemical equation should be the same for the correct answer (see answers in the table below).

14	What compound should be added?	Represent what you would see happening by a net chemical equation.
a	1st Any soluble chloride (Cl^-), e.g. dilute HCl, NaCl	Cl^- (aq) + Ag^+ (aq) $\longrightarrow$ AgCl (s), white precipitate
b	2nd: Any soluble sulphate (SO_4^{2-}), e.g. Na_2SO_4	SO_4^{2-} (aq) + Ba^{2+} (aq) $\longrightarrow$ $BaSO_4$ (s), white precipitate
c	3rd: any soluble hydroxide (OH^-), e.g. NaOH	$3OH^-$ (aq) + Fe^{3+} (aq) $\longrightarrow$ Fe $(OH)_3$ (s), red precipitate
d	4th No compound is added	Potassium ion (K^+) salt remains in solution. The salt can be obtained by evaluating the solution to dryness.

(4 points)

14 (e) Importance of following the order in steps 1- 4 in 14 (a-d):
To be able to precipitate one cation at a time, the order in which the anion is added is important. For example, starting with a compound containing chloride ion will only precipitate silver ion from the mixture, while starting with a sulphate or a hydroxide compound will precipitate two cations at a time. Sulphates, for example will precipitate both Ag^+, and Ba^{2+}, while hydroxides will precipitate Ag^+ and Fe^{3+}, hence separation cannot be achieved. **(1 point)**

Scoring

14. (a- c) If the student mentions the correct compound (or an anion) and writes correct net chemical equation to represent the expected reaction like in the sample answers above, he/she gets 1 point for each part. If the student mentions the correct compound without/ with wrong chemical equation or mention of wrong answer or no answer s/ he will get 0 point. In part d, 1 point is awarded, if the student mentions that no compound will be added and that the potassium salt will remain in the solution at the end of separation process.

14 (e) Students are given opportunity to give their reasoning why they would follow the order indicated in 14 (a-d) above. An example of the correct order (starting by precipitating Ag^{+} by any soluble chloride) and proceeding as in the sample answer above is expected. 1 point is awarded for the accurate explanation of the separation procedure. There is no partial explanation of this part of the question. Zero point is given for no explanation and/ incorrect explanation.

Total score for 14 (a-e) is 1 + 1 + 1 + 1+ 1 = 5.

15. (a) *Solubility product* is the product of the equilibrium concentrations of the ions in a saturated solution of a salt whereas *ion product* is the product of the concentrations of the ions at any moment in time (not necessarily at equilibrium). Solubility product refers to equilibrium constant, where as ion product it is a measure of the ions present in solution. The ion product at equilibrium is equal to the solubility product. **(1 point)**

(b) Although barium ions are toxic, 'barium meal' is not a problem because $BaSO_4$ has an extremely low solubility (will not dissociate to produce barium ions) in water, which protects the patient from absorbing harmful amounts of the metal. **(1point)**

(c) Solubility of $BaSO_4$ will be lower in 0.25 M Na_2SO_4 than in pure water because of the 'Common Ion Effect' (the SO_4^{2-} ions from Na_2SO_4 increases ion concentration in the solution and therefore lowers dissolution of $BaSO_4$) **(1point).**

Scoring

15. (a) If the student has the correct idea of the difference /relationship between the two concepts (solubility product & ion product) and provides correct description s/ he gets 1point. If the student provides wrong description or no answers s/ he gets 0 point. There is no partial answer to this part of the question.

15. (b & c). If the student states the correct answer supported by correct reason/ explanation (e.g. the solubility of $BaSO_4$ will be lower in 0.25 M) because of the common ion affect s/ he gets 1 point and gets 0 point for incorrect answer (the solubility of $BaSO_4$ will be greater in 0.25 M) or no answer.

Total score for 15 (a- c) is 1 + 1 + 1 = 3.

Appendix C1

Micro-scale chemistry experimentation (MSCE) activity survey of students

Purpose of the Questionnaire

Dear student, we would like to know what you think about the MSCE activities, which took place in your class recently. There are no right or wrong answers. Your individual opinion is what is required.

Personal information

Please provide information in the space below. Please be assured that your answers to this questionnaire will be treated confidentially.

Name: …………………………..	FORM:………………. Stream /Class ……… Date……………..
School..	Sex …………

How to Answer

For each of the following questions please tick (√) the rectangular box that describes best how you feel about a particular statement. Use the scale below to show your best response.

Scale: SD = **S**trongly **D**isagree (**1**), **D** = Disagree (**2**), **N**= **N**ot sure (**3**), **A** = **A**gree (4), **SA** = **S**trongly **A**gree (**5**)

Did you feel that Micro-Scale Chemistry practical activities:	**1 SD**	**2 D**	**3 N**	**4 A**	**5 SA**
Were linked into other parts of chemistry					
Helped you understand more about solubility and precipitation					
Helped you understand more about qualitative analysis					
Made you feel like learning more about the subject					
Helped you prepare for other topics in the syllabus					
Clarified some of concepts that you had difficulties with					
Made you enjoy your chemistry classes					
Made your head think					
Have given you confidence to carry out experiments by yourself					
Provided you with opportunity to use materials & equipment					
Made you feel working like a Chemist					
Made you actively participate in the lesson					
Increased your co-operation and sharing ideas with fellow students					
Made you feel very responsible about safety and environment					
Exposed you to an easier way of conducting experiments					

Scale: 1 = not at all helpful, 2 = of little help, 3 = moderately helpful, 4 = helpful, 5 = very helpful

How useful have you found the following activities in helping you to learn chemistry with Micro-Scale Chemistry approach?	**1**	**2**	**3**	**4**	**5**
Doing pre-lab exercises					
Doing prediction on what will happen in a particular experiment					
Doing experiments and seeing results myself					
Analysing and explaining experimental results					
Using instruction from the student worksheet					
Using plastic sheet to perform experiments					
Using grid paper to record observations					
Discussing experimental results in small groups					
Discussing experimental results as a whole class					
Teacher not explaining everything in the activity					
Teacher explaining the chemistry behind each experiment					
Doing follow-up assignment (homework) myself					

Please turn over the page to answer the following questions:

1. Please list two things you liked most in the Micro-Scale Chemistry lessons. Give reasons.
2. Please list two things you especially did not like in the Micro-Scale lessons. Give reasons.
3. How were these lessons different from your regular chemistry classes? Explain/elaborate.

APPENDIX C2
Student interview scheme (field-test)

0. What is your general impression about the Micro-Scale Chemistry based lessons/ practical work?

1. How have the lessons you did with micro-scale chemistry practical activities been different from your normal classes, if at all? (e.g. type of practical; teacher-student interaction, involvement in the learning activities, etc).

2. Of the activities you did in your chemistry practical on micro-scale, which ones were your favourites and why?

3. How have the MSCE practical work been different from other practical work you do in chemistry?

4. Did you find the discussions (in small groups and as a whole class) helpful in learning about solubility and precipitation topic?

5. What do you feel you have learned from the lessons with MSCE practical work?

6. Was the teacher nice to you?

7. In chemistry: what would you like more or less off?

8. Do you have any comments or other things you would like to say which you think might be useful/not useful about using micro-scale experiments in teaching and learning chemistry?

APPENDIX D1
Exemplary curriculum materials

PART ONE: EXPLANATION TO THE TEACHER

1. Introduction

The lesson materials are designed for the topic of *Solubility* and *Precipitation*. It is meant for the Tanzanian chemistry syllabus for secondary schools (A- Level, forms 5& 6). In the syllabus three sub-topics constitute this topic namely *concept of solubility*, *solubility product*, and *precipitation*. Content of the materials covers these sub-topics; specifically those directly linked to dissolution and precipitation reactions, and the common ion effect on solubility of sparingly soluble salts.

2. Micro-scale Chemistry

The materials in front of you dealt with the above topic in a micro-scale chemistry approach.

- Microscale chemistry refers to practical chemistry carried out on a reduced scale using small quantities of chemicals and often but not always simple equipment. There are different ways in which micro-scale chemistry can be practised, such as using well plate and acetate (plastic) sheets. In this material the later is used.
- The major focus in designing and developing these materials has been on introducing microscale chemistry practical activities as means to *promote active learning* in chemistry classrooms, as well as *reduce cost* for running practical work in schools.
- Experiments in these materials make use of drops of solutions on plastic sheets. Because many of the experiments on this approach are novel and uncommon, students may need time to get used to some of the techniques. For example, using a plastic pipette requires a steady hand and the application of the correct amount of pressure to the bulb. Still, if a mistake is made the drops may be quickly cleaned up with a tissue and very little chemical will have been wasted or time lost. With practice students should find the techniques easy to use. The emphasis throughout this material is on maximising for careful observation and interpretation. Students must get the opportunity to experience what happens and think about why it happens that way. The practical parts of these experiments can often be carried out rather quickly and thus create more time for post-lab discussion.

3. Teacher Support Materials

These materials consist of three parts: *the explanation to the teacher* (Part 1), *teacher support materials with student worksheets* (Part 2), and *appendices* (Part 3).

- Part 1 (the one you are reading now) describes the place of "solubility and solubility product" in the A-level chemistry curriculum and the audience; sequence and content of lessons, general issues in lesson preparation and execution, and the role of homework in mastering various concepts.
- Part 2 consists of *teacher support materials* (lessons 1-5) and *student worksheets* both of which have been prepared to respectively support and help teachers and students in teaching and learning the topic of solubility and precipitation by incorporating experiments into theory lessons. The student worksheets have been prepared to guide students in performing experiments on the micro-scale approach.

- The appendices give some additional information (e.g., solution preparation, pre-lab exercises and outline of topic content)

4. Sequence and content of lessons

Lesson	Lesson content	Time and Periods
1	Dissolution and precipitation of ionic compounds in aqueous medium and ionic equations.	160 minutes/ four 40-minute periods
2	Solubility guidelines and precipitation reactions of ionic compounds	160 minutes/ four 40-minute periods
3	Use of solubility guidelines and precipitation reactions in qualitative analysis for some common cations and anions.	160 minutes/ four 40-minute periods
4	Solubility product constant and prediction of precipitate formation for sparingly soluble salts	160 minutes/ four 40-minute periods
5	Solubility and the Common Ion Effect	80 minutes/ two 40-minute periods

Note: The difference in duration originates from the difference in content coverage and the experiments involved for each lesson. All lessons are planned to fit within the time allotted for practical work (2 double periods of 80 minutes each) in the school timetable.

5. Preparation and execution of lessons

General issues

Most of how-to-do suggestions have been given in each lesson, however, the following issues have to be considered seriously for a successful practical lesson.

- List all equipment required per group and the total quantities, list all solutions, including concentrations and quantities required. Check your stock and list all solutions you have to prepare (see guide in Appendix 2.2& 4).
- Try-out before hand all the experiments to make sure the reagents are working well.
- Think about and list down the problems that you expect students might encounter in doing a particular experiment and how you will proceed helping them. For example, difficulties related to manipulation of apparatus, colour changes. If students lack the required skill, such as use of plastic sheets and pipettes demonstrate this before starting with a practical.
- Work out how you are going to distribute the apparatus and materials and how you are going to collect at the end of the lesson.

How to organise your practical work

- Grouping of students: Make as many groups as your equipment and space allow. An ideal situation would be 2-3 students per group. Set groups according to proposed arrangement (see group arrangement in the lesson material), and observe gender balance. Maintain same groups unless there is a good reason to reshuffle. Specify roles each member need to play to carry out the activities. Ask each group to have the chairperson and the secretary to co-ordinate group tasks (e.g. who will collect the equipment, chemicals, and present group results).
- Introducing the practical: This part of the materials has been well explained in each lesson. Nevertheless, do not forget the purpose of practical activities and what students should do to reach this purpose.
- Monitoring progress of practical activities: Walk around in class to monitor student work. Refer to the procedure where necessary; check how students are making observations and recording results, discussing and reflecting on the results and procedure. Make sure that students follow safety regulations.
- Cleaning up: Let groups clean the reaction products on the acetate sheets after they have finished recording. Always let groups return all the unused materials at the end of the practical. Shelve the solutions yourself immediately after the practical for future use.

Questions for consolidating learning outcomes/ homework

- Mastering concepts cannot be achieved through explanations only. Reflection on and deepening of concepts is absolutely necessary. Doing exercises can achieve this, however, class time is limited. You will therefore have to give part of the exercises as homework. Few questions have been set at the end of each lesson for homework. Try always to provide students with necessary feedback over the exercises. A variety of ways can be used for this. One way is to go over the exercises in class (involving students as much as possible), another way is to write the correct answers on a large sheet and put it on the notice board from which students make their own corrections.

APPENDIX D2
Final version of exemplary lesson materials

Teacher support materials (lesson 3)

3

Using solubility rules in the qualitative analysis of ionic compounds

1. **Introduction**

- Detectives in mystery novels often rush evidence from the crime scene to the laboratory for analysis. In this lesson, students will learn how to become a chemical detective. In the laboratory, there are six (6) *labels that have fallen off reagent bottles containing aqueous solutions of different chemicals*. *It is difficult to tell, which label belongs to which bottle*. Therefore, students will have to carry out *qualitative analysis* to determine the identity of chemical composition of unknown solutions (labels) on the basis of their reactivity with other solutions and by using solubility rules learned in lesson 2. Solutions are to be tested and their characteristic reactions noted. The analyses students will perform are based upon the data that each solution contains one ion, which will give a characteristic reaction by which the identity of the solution can be obtained
- The experimental set-up contains a sample of six (6) solutions, which are labelled A- F. An additional set of known solutions from the laboratory ledger is provided. The known solutions are identical to the unknown set. They are, however, not in the same order. No other chemical compounds have been provided and none of the samples are distilled water only.

2. Objectives of the lesson
It is expected that at the completion of this lesson students should be able to:
Work with small quantities of chemicals confidently; observe the reactions of common anions and cations in solution to simple chemical tests; and identify the ions present in an unknown solution based on the logical application of chemical tests and solubility rules.

3. Resource materials and further reading
United Republic of Tanzania (URT): Chemistry Syllabus for Secondary Schools, Form V-VI. Ministry of Education and Culture (MOEC), 1997. Topic 2.7, pp.37-39.
E.N. Ramsden (1994). A-level Chemistry 3rd Ed. England. Stanley Thornes Publishers Ltd. (pp. 273-277)
Tanzanian Institute of Education (1995). Advanced level inorganic chemistry. Part 1 & 2. Tanzania: Dares salaam University Press.

4. Preparation
Prepare the following requirements for the experiment.
Apparatus
A4 reinforcement pocket paper (i.e. plastic reaction sheet, 1 per group), paper grid (see Tables 3.1 & 3.2, 1 per student), Small plastic pipettes (one for each solution), 250mL beaker (1 per group), 50 mL plastic beaker (2 per group), Rolls of toilet paper (2), Masking tape (4 pieces per group), Toilet soap (1piece), toothpick (1 packet).

Chemicals

- Photo film containers (ca. 50mL) labelled **A**, **B**, **C**, **D**, **E**, and **F** the following aqueous solutions: barium chloride, sodium sulphate, lead (II) nitrate, sodium hydroxide, silver nitrate, and sodium iodide. All solutions at the concentration of 0.1 mol / litre except 0.2 $molL^{-1}$ for silver nitrate solution.
- Distilled water (at least 250 ml per group). Use bottled water 'Kilimanjaro' if not available.
- All reagents containing the unknown solutions of ions for the experiment must be prepared and tried out before the lesson day to check if everything works well (*See solution preparation guide in Appendix 2.2*)

5. Safety

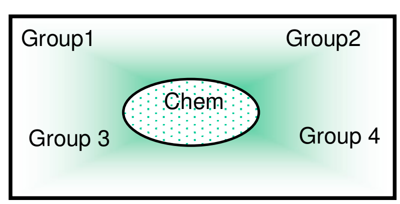
Unknown chemical may pose unexpected hazards. Wash your hands immediately upon contact with chemicals. Avoid breathing vapours from chemicals. Lead solutions are poisonous so are barium solutions. Silver nitrate causes stains on your skins and potassium dichromate is a strong oxidizing agent

6 Lesson plan and Timing (min)

Time	*Student activities*	*Teacher role*
15	Representatives of small groups present scheme to separate ions from a mixture of solutions as part of pre-lab exercise.	Let students present their answers of the pre-lab exercise. Explore students' alternative ideas/misconceptions.
25	Small groups perform chemical tests for known and unknown solutions, observe and record results.	Monitor group activities. Check student participation in the activities (e.g. mixing drops, recording).
40	Compare and analyze experimental results to identify unknowns A – F based on experimental results.	Visit groups and provide support or guide
25	Pairs of groups present their results, analysis and conclusion to the whole class.	Lead presentation and do appropriate timing. Note down emerging ideas for discussion from each presentation.
40	All students discuss presentations. Focus on differences of experimental results between groups and also in relation to their pre-lab exercise.	Focus student discussion by relating observed results to solubility rules and list of solutions. Provide correct identity of unknown solution to conclude the lesson.
05	Copy simulated problem for homework and note down assessment guidelines.	Assign simulated problem and talk on assessment guidelines.
10	Clean up work places and apparatus Return all apparatus and unused solutions	Make sure that all unused solutions and sheets are returned and all wastes are put in proper waste container.

7. Group work

Set framework for small group activities, for example, the number and roles of members (preferably 3 students per group), arrangement of chemicals, and duration of activity, recording data and important resources. See possible table or work bench arrangement on the right.



8. Start of lesson

Begin your lesson with students presenting proposed separation scheme to separate each of the four ions (Ag^+, Ba^{2+}, Mg^{2+}, and or K^+) from others as per pre-lab exercise sheet (Appendix 3.1). Explore and note any emerging students' alternative ideas for discussion. Give information to students on the purpose of the experiments in activity 1 and 2. Guide them through the activities.

Experiment 1

Several solutions are mixed together, two at a time, to determine which combinations produce a precipitate and, if so, the nature of the precipitate (Table 3.1). After all of the combinations are tried and the results recorded, the students are expected to be able to recognize the same chemicals in unlabeled containers of solutions **A–F** (Table 3.2**).**

- Let students use key to record observations as the one provided in lesson 2.

Solution of	$BaCl_2$	Na_2SO_4	NaOH	$Pb(NO_3)_2$	NaI	$AgNO_3$
$AgNO_3$						
NaI						
$Pb(NO_3)_2$						
NaOH						
Na_2SO_4						
$BaCl_2$						

Observation Table 3.1: Reactivity grid of combinations of known aqueous solutions

Experiment 2

Six aqueous solutions (A-F) are mixed, two at a time, reactions noted and studied to identify the ionic composition of each solution

Solution of	**A**	**B**	**C**	**D**	**E**	**F**
F						
E						
D						
C						
B						
A						

Observation Table 3.2: Reactivity grid of combinations of unknown aqueous solutions

9. Conclusion of lesson

Conclusion must be derived from the analysis and discussion of experimental results, and with the help of the solubility rules for ionic compounds in water. Expected identity of solutions is listed below.

Label	Solution Chemical name	Formula	Ions present Cations	 anions
A	Lead (II) nitrate	$Pb\ (NO_3)_2$	Pb^{2+}	NO_3^-
B	Barium chloride	$BaCl_2$	Ba^{2+}	Cl^-
C	Sodium hydroxide	NaOH	Na^+	OH^-
D	Silver(I)nitrate	$AgNO_3$	Ag^+	NO_3^-
E	Sodium sulphate	$Al_2\ (SO4)_3$	Al^{3+}	SO_4^{2-}
F	Sodium iodide	NaI	Na^+	I^-

10. Assignment

Suggested question for group homework to consolidate lesson outcomes

After a successful completion of your advanced secondary education in chemistry you are invited to a written interview with the office of the Chief Chemist in Lake Zone, describe how you would proceed answering the following question:

Recently, fish in Lake Victoria began to die in large numbers. The lake is down the stream from copper mine, also known to contain some lead and silver ores. Copper (Cu^{2+}) and Lead (Pb^{2+}) ions are known to be lethal to fish. A sample of the mine effluent has been sent to the laboratory of the Chief Chemist for analysis. Devise a qualitative analysis scheme to identify (if either) of the above cations is present in water. Your qualitative analysis scheme should show which reagents you would use and what conclusions you could reach at each step. Where a reaction could occur, write a net ionic equation (with state symbols).

11. Teaching notes

Results

After adding reagents to the appropriate squares on plastic sheets, interactions between some combinations of ions will be observed. Not all combinations will produce a precipitate or will result in a colour change as evidence of chemical reactions. Table 3.3 shows expected results from the solution combinations. "I" for insoluble indicates where precipitates occurred, "s" for soluble indicates where precipitates did not occur, and "ss" for slightly soluble indicates where precipitates occurred just a little and not immediately. The colours: shown brown, cream and white show the precipitate that is formed.

Table 3.3: Expected observation results

Solution of	A	B	C	D	E	F
F	i yellow	s	s	i cream	s	
E	i white	i white	s	s		s
D	s	i white	i brown		ss white	i cream
C	i white	s		i brown	s	s
B	i white		s	i white	i white	s
A		i white	I white	s	ss white	i yellow

12. Analysis and Discussion

With the help of solubility rules for ionic compounds, the list of solutions, and the observed interaction of solutions, guide students to identify the ionic composition for each of the six solutions (A-F). The identification process should start with the most identifiable precipitate and branches out from there. From the observation table the most *characteristic precipitate* is the *brown/ thick tan* of silver hydroxide. Since this precipitate is in the squares containing solution D and C, solution C and D must contain the silver ion and hydroxide ion sources. Further observations show that solution D also form precipitates with B, E (white) and F (cream) while C does not. Therefore D must contain the silver ion source and solution C the hydroxide. We now have two of the six chemical solutions identified.

The identification process can continue by identifying chemical species with the precipitates associated with hydroxide ion. Only lead (II) hydroxide is a possible precipitate and it occurs when C is combined with A. Thus, A contains lead ions. Lead iodide is a *characteristic yellow colour* and appears when solution A combines with solution F. Therefore it can deduce that iodide is in solution F. We now know all precipitates with iodide; we need a different solid to sort out the last two solutions. After looking through the solubility rules and precipitate colours, we note that barium makes *a white solid* when combined with sulphate. This pattern is noted when B is mixed with E hence solution B contains barium and solution E contains sulphate. We have now identified all species (see conclusion above) by deductive reasoning through identification of the precipitates by employing solubility rules and the list of possible reagents

Key Terms and Chemical Concepts

Qualitative analysis (QA): The process of determining the composition of a sample of matter by conducting chemical tests. QA is a technique used to separate and detect *cations* and *anions* in a sample of substance. QA tells what the compound is, but not how much is present.

Qualitative Techniques (QT) for inorganic analysis is used to identify cations and anions in aqueous solution by simple reactions, mostly involving the production of a precipitate, evolving a gas or a visual colour change.

APPENDIX D3
Student worksheet

3. Using solubility rules in qualitative identification of ions in unknown solutions

3.1 Introduction

The reaction of an ion with standard reagents which results in *a visual colour change*, *precipitate* or *generation of a gas*, is a standard method of identifying that particular ion in solution. The experiment you will do in this lesson is an investigation of this principle. You will employ solubility rules learned in lesson 2 and observed reactions to answer the following question. *On your workbench you have six (6) chemical solutions whose labels have fallen off reagent bottles. It is difficult to tell, which label belongs to which bottle.*

You will perform a series of chemical tests to identify the six solutions on the basis of their reactivity with other solutions, and reactions of known solutions. These solutions are to be tested and their characteristic reactions noted. Each solution contains one ion, which will give a characteristic reaction by which the identity of the solution can be obtained.

3.2 Materials

Apparatus

- Plastic reaction sheet and grid paper (1/group), observation grid paper (1/ student, see Tables 3.1 & 3.2), small plastic pipettes (1 for each solution), Toilet paper, Masking tape, waste beaker (1 per group), rinse beaker (1/group), stirrer (toothpick).

Chemicals

- SET I: 6 known aqueous solutions (5 from sodium salts and 1from barium salt).
- SET II: Small amounts (5mL each) of unknowns aqueous solutions **A - F**.
- Distilled water, if not available use bottled water 'Kilimanjaro'.

SAFETY DURING THE EXPERIMENTS

- The experiments in this lesson involve lead, barium and silver compounds, which are toxic. Silver nitrate solutions stain skin. Avoid contact with silver nitrate solutions. Wash all spills immediately with plenty of water.
- To clean the reaction products on the plastic sheets, use a piece toilet paper and dispose it in the waste container provided by your teacher or lab technician.
- Always wash your hands properly with soap and water after you finish each experiment.

3.3 This is what you do

Set up the procedure to identify the correct name for each of the solutions in the containers A, B, C, D, E, and F.

Hint:
Follow table 3.1 & 3.2 to help you organize your experiment. Try mixing known solutions, two at a time, to determine which combinations produce a precipitate, if so, the nature of the precipitate. After all the combinations have been tried and the results recorded, perform similar combinations using unknown solutions. Use the results from both experiments to determine the correct identity of each solution in unlabeled solutions. Use 1 drop from each solution for making all possible combinations of the solutions.

3.4 This is what you see happening
Did a precipitate form? NO 'i' YES 's' (also not the colour)

Solution of	$BaCl_2$	Na_2SO_4	NaOH	$Pb(NO_3)_2$	NaI	$AgNO_3$
$AgNO_3$						
NaI						
$Pb(NO_3)_2$						
NaOH						
$Na_2 SO_4$						
$BaCl_2$						

Observation Table 3.1: Reactivity grid of combinations of known aqueous solutions

Did a precipitate form? NO 'i' YES 's' (also not the colour)

Solution of	**A**	**B**	**C**	**D**	**E**	**F**
F						
E						
D						
C						
B						
A						

Observation Table 3.2: Reactivity grid of combinations of unknown aqueous solutions

3.5 This is what you are looking for

Use solubility rules generated in lesson 2, the list of known solutions provided in lesson 2, and the observed reactions to write the identity of each solution.

Solution label	Identity	Solution	Identity
A		D	
B		E	
C		F	

Post-lab question: EXPLAIN how you arrive at the identity of each solution in the table above.

SUMMARY
Qualitative analysis (QA): The process of determining the composition of a sample of matter by conducting chemical tests. QA is a technique used to separate and detect *cations* and *anions* in a sample of substance. QA tells what is the compound, but not how much is present.

Qualitative Techniques (QT) for inorganic analysis are used to identify cations and anions in aqueous solution by simple reactions, mostly involving the production of a precipitate, evolving a gas or a visual colour change.

Homework (work in pairs)
Suggested question for homework to consolidate lesson outcomes

Suppose after a successful completion of your advanced secondary education in Chemistry you are invited to a written interview with the office of the Chief Chemist in Lake zone, describe how would you proceed answering the following question:

Recently, fish in Lake Victoria began to die in large numbers. The lake is down the stream from copper mine, also known to contain some lead and silver ores. Copper (Cu^{2+}) and Lead (Pb^{2+}) ions are known to be lethal to fish. A sample of the mine effluent has been sent to the laboratory of the Chief Chemist for analysis. Devise a qualitative analysis scheme to identify (if either) of the above cations is present in water. Your qualitative analysis scheme should show which reagents you would use and what conclusions you could reach at each step. Where a reaction could occur, write a net ionic equation (with state symbols).