Practical Activity in Ethiopian Secondary Physical Sciences: Implications for Policy and Practice of the Match between the Intended and Implemented Curriculum[1]

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Abstract: *This paper reports on a study which examined the secondary physical sciences curriculum in Ethiopia with a particular focus on practical work. It describes the intention and realization of the science curriculum in terms of that which is intended by policy makers and curriculum developers and that which is implemented by classroom science teachers. Ethiopia's new Education and Training Policy and Sector Strategy (EMPDA, 1944a and b) advocates – as did its predecessors – that science be taught emphasizing a problem-solving, practical approach in the classroom. The main methods used by the study to gather data were: analysis of documents – policy statements, textbooks, examination papers; classroom observation; and analysis of 80 science lessons in four sample schools, enriched through interviews with a range of those involved – from policy makers to students in schools. The study revealed that the link between policy and practice in secondary science with regard to practical work was always tenuous. Broad and specific curriculum objectives as well as the teaching and learning activities prescribed in the textbooks were neither internally coherent nor congruent with the stated policy objectives. Furthermore, assessment practice and school practice did not match intentions. As a consequence, Ethiopian secondary students do not receive the practical experiences specified in the official science curriculum.*

Background to the Study

Since the overthrow of the Marxist military junta leading to the establishment of the Transitional Government in 1991 and the Federal Democratic Republic in 1995, Ethiopia has embarked on reforming its socio-economic and political structure in line with free market economy and political liberalization. It is intended that the change will

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[1] Reprinted from **Research Papers in Education Vol. 15, No.2** by request of Samuel Bakalo, one of the authors

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promote economic growth in one of the least developed countries in the world. To facilitate the objectives of economic and social progress, different sector policies have been introduced. Education and training are considered to be important agents in achieving the required development and to be high priority.

A growing recognition of the state of education – which Negash (1990) described as being in crisis due to irrelevant and inappropriate methods, including failure to incorporate relevant practical experience – has led to the formulation of the new Education and Training Policy and Sector Strategy (EMPDA, 1994 a and b). The policy advocates a problem-solving approach to teaching and learning at all levels of education. It addresses such issues as the purposes of education, the context for the curriculum, teacher education, and other conditions essential to foster more active approaches in the classroom. It recognizes that wholly expository styles of teaching of factual information in preparation for examinations which themselves emphasize pure recall may be poor development for citizenship. In science education, the ambition is to devise a curriculum and methods of instruction to promote learners' conceptual and procedural knowledge by closely integrating theoretical and practical work. Accordingly, primary science education reform is underway and the new secondary science curriculum is to be phased in from the beginning of the Milennium.

Notwithstanding the importance of the current reform to promote educational excellence, there were similar initiatives in the past largely neutralized by problems which still exist and which may inhibit the implementation of the present policy. The previous socialist and imperial governments' education legislation had advocated that science was to be taught, at least partially, as a process of practical inquiry (UNESCO, 1961; MOE, 1980/4/6; EMPDA, 1987/8). However, such rhetoric was rarely translated into a workable curriculum or active classroom practice and the focus on rote learning of factual information in preparation for examinations persisted. One of the shortcomings of educational reforms in Ethiopia appears to be the apparent confusion inherent in conceptualizing practical work (Bekalo, 1997). There is an assumption among Ethiopian science educators, including teachers, that practical work in the sciences means only laboratory work involving relatively sophisticated and imported expensive apparatus. Alternative practical activities, such as those that can be done outside the laboratory or with locally available materials are not considered to be practical work; they are also perceived as low status activities (Bekalo, 1997). Furthermore, Bekalo's study revealed that the majority of educators thought the purpose of practical work was only to confirm scientific "facts". They reflected the traditional aphorism. "I hear and I forget, I see and I remember, I do and I understand", as the only justification for doing practical work in science.

One implication of this, as noted by Allsop (1991), for many developing countries, has been to produce a science curriculum which places a considerable demand on resources which might simply be beyond the means of individual schools, or even the country to supply. This pervasive, stereotypical view of the nature of science and its activities, is congruent with the 1950s and the 1960s curricula, imported from the West, which demanded expensive resources if they were to be implemented in line with their stated objectives. It resulted in aspects of what Hodson (1996a) refers to as the inappropriate use of practical work. Thus not only should there be a clarity in the definition of what constitutes practical activity, but there is also a need to be clear about the roles and purposes of the range of practical opportunities needed to develop a problem-solving approach in school science education in Ethiopia. These issues have been addressed in an extensive literature that examines the rationales for the role and purposes of the different types of practical work in school science and the variety of emphases in the context of individual countries (see for example Woolnough and Allsop, 1985; Millar and Driver, 1987; Allsop, 1991; Claxton, 1991; Nott, 1996; Hodson, 1996b). Science education reformers in Ethiopia may need to consider these and other detailed discussions of practical work developed elsewhere (Hodson, 1990/2/3, 1996a, Woolnough, 1994;

White, 1995; Duggan and Gott, 1995), and reflect on their implications for policy development and effective implementation of the evolving Ethiopian science curriculum.

However, in view of the fact that policy implementation is a government priority, there has been little time and opportunity perhaps for educators, particularly curriculum developers, to unravel an old curriculum and identify what might be changed or modified. Furthermore, as Ethiopia moves away from a centralized to a decentralized political system, the education system has been caught in the transition. The difficult task of understanding and implementing the new educational objectives at regional level lies ahead with the limited human resources available at present. Indeed, it is not evident that there is the educational expertise necessary for the implementation of a policy which engenders a practical approach to science teaching (ESDP, 1997/8; Bekalo and Welford, 1999).

Focus of the Study

This paper describes the present Ethiopian secondary physical sciences curriculum through its published materials with a particular focus on the provision of practical experiences. It then examines the translation of that curriculum into action in classrooms in secondary schools and teacher-training colleges.

These dimensions of the curriculum are what Livingston (1985), Goodson (1988) and the National Science Foundation (1992), among others, describe as the 'intended' and the 'implemented' curriculum. The intended curriculum is primarily concerned with the official curriculum materials from policy papers to officials textbooks (in the case of Ethiopia). The implemented curriculum is concerned with what actually takes place in classrooms. In an ideal education system there will be a complete match between the two aspects of the curriculum.

In this paper, practical work is referred to as an activity that promotes active learner participation in learning. This sometimes means 'hands-on' activity involving equipment, but also encompasses a range of other ways of working, including teacher demonstration, group discussion of problems and their solutions, interaction between student and student or student and teacher. It may involve individual activity such as measurement, observation and investigation. It can take different forms - from experiments to pencil and paper activity - and may take place in the laboratory, classroom or elsewhere. The purposes of the most common types of practical work which have underpinned Ethiopian and several other curriculum publications are summarized in the following section.

It is clear that Ethiopian policy makers and curriculum developers have not differentiated purposes for secondary science in the curriculum itself. Science is seen as functional in preparing both a body of future scientists who can play a key role in the development of the national economy and in having the boarder purpose of developing scientifically literate citizens. However, it is contended that both purposes require that the school science curriculum should have a focus on practical work. Future scientists will be expected to be both knowledgeable and skilled. Equally, citizens will not be fully scientifically literate unless they have received a balanced curriculum which promotes both conceptual and procedural knowledge.

The focus in this paper on practical abilities, therefore, has direct relevance for both purposes of the science curriculum. For science education to cater for all students, without assigning priority to either immediate interest or future opportunity, it should aim to achieve two goals – to provide students with sufficient knowledge of concepts required to make sense of the world around them, and of procedures required to understand how concepts are investigated. This view can be pursued on scientific, philosophical and pedagogical grounds. Science education completely devoid of the concepts or the processes by which knowledge is generated becomes merely organized common sense which is neither science nor education (Van

Praagh, 1983 Screen, 1986; Gott and Mashiter, 1991; Hodson,1996b). The nature of science and scientific activities reinforces the idea that concept and process are inextricably linked, thus it is worth pursuing the kind of practical education which involves procedural operation and construction of science concepts. There is a need to design appropriate curriculum and instructional strategies which allow pupils to experience a range of problems that generate the conceptual and procedural knowledge demanded both in and out of classrooms. Practical work and defined here forms the basis for this kind of curriculum.

The paper looks at the present situation of secondary science education in order to comment on constraints on the development of practical work in school science. Data was gathered during a one-year field study in Ethiopia, and the sources of data included published and unpublished documents, classroom observation in schools and teacher-training colleges, interviews with educators, ministry officials, curriculum developers, teacher-trainers and teachers (Bekalo, 1997).

Procedures and Methods of Analysis

Description of the intended curriculum demanded analysis of policy documents, curriculum and assessment materials and textbooks to provide information about how practical work was conceptualized in the sources available to teachers to guide their practice.

The Socialist Government of Ethiopia, from the time of the revolution in 1974 until 1991, made many policy pronouncements, but it did not issue any officially published educational policy statements. It tried, through decrees and directives, to bring change to the national curriculum, but it was not able to set a clear educational policy or bring a real educational change. The published curriculum textbooks and guides were a slight modification of the pre-1974 Imperial Government education documents. These have served as educational directives for the 'transitional curriculum' from the 1970s to the present time. These were the materials available for analysis.

To see how the intended curriculum in science articulated its objectives with respect to active learning and the promotion of practical experiences, the study analyzed

- curriculum guides which embodied the policy direction, provided specific subject educational objectives and gave instructional guidance;
- Grade 10 and 11 textbooks which amplified the advice with operational details; and
- samples of Ethiopian Secondary School Certificate Examination (ESLCE) and school examination paper to gain a feel for the explicit and implicit curriculum priorities for teachers and students.

Two analytical procedures were used for the curriculum materials. In the first, each chapter in the textbooks and guides was taken as the unit of analysis, the practical activities on offer were noted and classified into different categories (the framework was the same as used to describe practical activity observed in classrooms and is described in detail below). Each activity was noted on a grid to record the frequency of the use of each type of activity. The same analysis scheme was applied to examination papers to examine the frequency of testing of the range of curriculum objectives.

In the second procedure, the purposes of the tasks were carefully examined to measure the correspondence between what they were stated to be about and the experiences which the activities would actually offer. The resultant matrix thus provided a summary of task types, task purposes and curriculum objectives targeted.

The study of the implementation of the curriculum comprised an analysis of classroom transactions gathered through a series of classroom observations. A total of 80 lessons were observed in four sample schools, characterized by urban, semi-urban and rural features. Additionally, 40 sessions in two principal teacher-training colleges were studied in the same way to get an insight into how student teachers were trained with regard to practical work.

The framework for analysis was based on the classifications of practical work suggested by Gott *et al* (1988) who drew upon the assessment framework of the APU science programme (Archenold *et al.*, 1988). These are:

Basic Skills: measurement, selection and use of appropriate instruments, following instructions and construction of tables, charts and graphs from data generated from students' experiments or drawn from other sources.

Observation: observing similarities or differences and changes between objects and/or events, generating classification of patterns, identification and description of the relationships between variables under study.

Illustration: showing (usually through teachers' demonstration) given phenomena, concepts, laws or principles in action.

Enquiry: 'discovering' a concept in a series of more or less structured activities (usually designed for students) to carry out investigation following instructions to find out or confirm or 'see' a concept in action by themselves.

An enquiry-based approach allows pupils to experience the concept under study as first hand through structured experiments designed to lead them to 'discover' the underlying concept and thereby providing an opportunity to develop limited experimental skills such as following instructions.

Investigation: designing and carrying out an entire investigation which includes examining the data resulting from the investigation and drawing conclusions from it. This involves identifying a problem and formulating a hypothesis; identifying, systematically varying and controlling relevant variables; deploying effective measurement strategies, collection of data and its interpretation before drawing a conclusion. Here, concepts may be needed to solve the problem but they do not constitute the only end point for the activity.

The purpose of the investigation activity is to enhance both conceptual and procedural knowledge

Two classroom observation schedules, referred to here as Record Sheet 1 and Record Sheet 2, were developed to record each lesson observed and to facilitate the subsequent analysis of activities. The nature of practical activity was recorded on Record Sheet 1 using the framework above. Where no practical activity took place, Record Sheet 2 (based on a modified form of Flanders' categorical system known as FIAC (Flanders, 1970), was used. Teacher pupil interactions were recorded every 3 minutes rather than at the 3 second intervals used in FIAC. The decision to use a 3 minute period was reached after a pilot study showed that student activity was confined mainly to listening and note taking. The observations allowed description of the types, purposes and frequency of classroom tasks and activities, the organization of the task, teachers' and students' roles and the range of materials used.

Some 50 separate interviews were conducted. These included discussions with a range of people involved in the education process: Ministry officials responsible for policy determination; curriculum developers and examiners; teacher-trainers; teachers; and students in schools and colleges. Trainers, teachers and students were interviewed before and after classes were observed. The interview schedules were developed based on the Hierarchical Focusing Interview techniques of Tomlinson (1989). Questions probed areas such as respondents' understandings of the purpose of practical work, the focus of examples of practical activity, specific lesson objectives and the realization of objectives in practice. The outcomes of these interviews were to amplify and enrich the data from the materials analysis and the observations. Insights from the interviews have been used to describe and explain the match between the intended and implemented curriculum in action in Ethiopia.

Results and Discussion: The Intended Curriculum

Analysis of the curriculum guides

The general curriculum objectives for secondary science (EMPDA, 1987/8 (pp. 1-5), 1989a, b (pp. 1-4), c and d) state that science courses offered in secondary schools 'should help students to acquire:

- A thorough foundation of knowledge (cognitive behaviour)
- Practical skills in application of knowledge (psychomotor behaviour)
- Conviction of the value of knowledge (affective behaviour)

More specific objective statements are given for subject areas. The curriculum guides set out specific statements of what science teaching is to achieve by the end of the secondary school in terms of cognitive, psychomotor and affective behaviours. These are summarized for chemistry and physics (Table 1).

Table 1: Statements of the Aims of Science Teaching – Extracts from Grades 10 and 11 Physics and Chemistry Curriculum Guides

Knowledge (cognitive behaviour)	skill (psychomotor behaviour)	development of convictions of the value of knowledge (affective behaviour)
Knowledge of chemicals, physical phenomena, facts, principles, laws and regularities	interpreting experimental results, making correct deductions from tested hypotheses	contributing to the formation of philosophical, political and moral convictions to enable understanding of the laws and regularities of nature which are dialectical;
Knowledge of procedures and techniques for carrying out experiments	handling scientific equipment carefully and setting apparatus for experiments	working in a society
Mental operations like imagining, analyzing, synthesizing, proving, comparing, reasoning, generalizing, classifying, grouping;	measuring physical quantities and using SI units	perceive the laws of nature that act independent of our consciousness
Developing inquisitiveness, critical thinking and scientific evaluation, eagerness for learning	using models to stimulate and explain certain aspects of the objective reality	develop consciousness, carefulness and neatness in observing and experimenting
	observing processes and phenomena carefully	
	carrying out a sequence of manipulation towards a desired and systematic way of solving problems	
	using experimental methods in every day life to acquire more knowledge	

The secondary science educational objectives appear, at first glance anyway, to emphasize a practical approach to teaching and learning. The statements are evidence of the desire to contribute to the development of students' practical abilities through a practice oriented approach. There is much reference to activities such as hypothesizing, observing, experimenting, inferring and communicating; terms which are common to curricula materials worldwide (Screen, 1986; DES, 1985, 1991; AAAS, 1989, 1993). It is worth noting, however, as is shown in the summary given as Table 1, these recommended activities are spread between 'cognitive behaviour' and 'psychomotor behaviour'. That there is no explanation for their placement might suggest that the policymakers and curriculum developers were themselves unclear about the role of practical work in realizing the different sorts of objectives.

The curriculum guides recommend pedagogic strategies for practical work, suggesting the teachers should use a variety of teaching methods (e.g. lecturing, discussion, demonstration, the inquiry method) to achieve the curriculum objectives. For instance, the instructional strategies suggested for the units: Electricity and Magnetism (Grade 10 Physics) and Wave and Sound (Grade 11 Physics) are typically developed as follows:

> Most of the subject matter mentioned in the unit **Electricity and magnetism** can be imparted using discussion and experimental activities. **Students** can be asked to observe, describe and explain the process and define the result of the experiments ... Experiments on suspension of magnets, magnetic field and law of magnets can be done by the **teacher** but **students** should be involved. Breaking a magnet should not be done; the idea can be explained using already acquired knowledge of magnetic properties. For the practice activities on magnetism equipment (2 magnets, magnetic needle with suspension, iron filling and some bodies made of iron) are necessary (EMPDA, 1987, p.8).

and:

> **Mechanical wave production** is taught better if experiments are employed. Water and a piece of rope are available materials to be used in the **demonstration** of the generation and propagation of mechanical wave ... **Teachers** should emphasize the transfer of energy in all the activities and demonstration of waves. The difference between a pulse and wave must be made clearer using demonstration. **Students** should do some of the activities suggested in groups, observe the transverse of energy in waves ... The use of demonstration is essential to teach sound waves. Every **student** in the class can generate sound, so ask them to do so. The

> experience. Swimming under water in a pool, and putting our ears on the railway lines are examples that show sound travels in liquids and solids respectively. (EMPDA, 1989a, pp. 50-51).

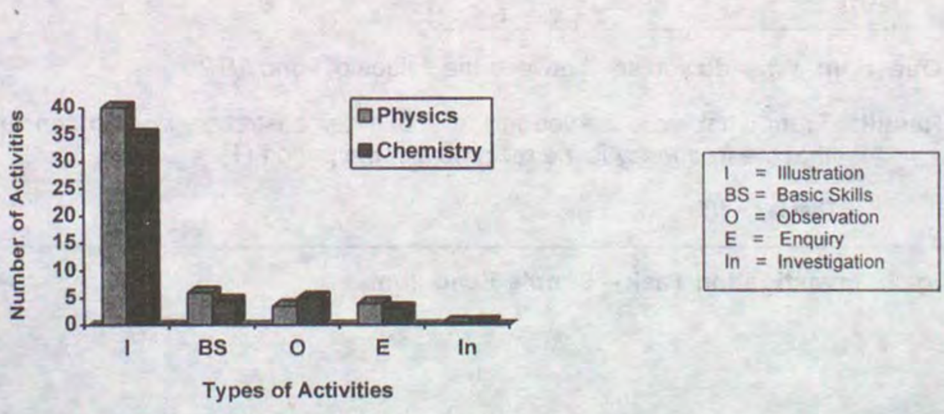
Such statements show the extent of the use of demonstration as instructional strategy probably in an attempt to recognize the difficulties teachers face in providing their classes with sets of the equipment needed to carry out class experiments. There is no reference made to instructing students in the planning and carrying out of practical investigation by themselves although these are among the science curriculum objectives. The detailed analysis of all the instructional strategies recommended for practical work in all other content areas gives the same picture.

Practical Activities in the Textbooks

The science textbooks contain a variety of practical activities to support the realization of the curriculum objectives. They are always shown in the text under one of the titles *Activity*, *Experiment* or *Tasks*. Because these terms are used interchangeably, it is difficult to know whether the writers have intended them to be seen as separate classes of practical work.

A total of 105 activities (55 Physics and 50 Chemistry) were identified from the relevant textbooks. These were classified under the five categories already described and the taxonomy is shown in Fig. 1.

Fig 1: Different types of Practical Activities in the Textbooks (n=105)



Most of the practical tasks on offer in both physics and chemistry textbooks were classified by the analysis intended to promote concept acquisition through illustrative experiment. The other types of practical activities which the texts suggested that students carry out were much rarer.

Furthermore, the judgement was that although there were activities in the texts instructing students to 'measure', observe', 'plan' and 'investigate', the tasks actually set for such purposes did not appear to encourage active decision making relating to these processes. In activities described as 'investigation', students were told exactly what they should measure, observe or investigate. An example pendulum 'investigation' activity from the Grade 11 Physics textbook is shown as Fig. 2.

Let us **investigate** the relation of f and T using an oscillating pendulum

Apparatus:

A simple pendulum-a metal bob suspended by a string on a rigid body – and a stop-watch

Procedure

1. Suspend the pendulum from a rigid body as shown.
2. Set the pendulum swinging with an amplitude of somewhat less than 10 degrees.
3. Determine the frequency by counting the number of swing in 1 minute, and dividing the number by 60 to find the number of swings in a second. Make at least three determinations like this.
4. Determine the period of swing by measuring the time taken for 5 swings and divide this by five to find the time taken for one swing. Make at least three determinations like this and put the result in the table given below.

Number of Measurement	1	2	3
Frequency (f)			
Period (T)(s)			
$1/Ts^{-1}$			

Question: What do you see between the values of f and 1/T?

Result: From what we observed in the above demonstration we can conclude that the frequency is the reciprocal of the period (T).

That is f = 1/T

Fig. 2: Investigation Task – Simple Pendulum

The detailed instructions would appear to shift the purpose of the activity from investigation to the confirmation of taught science concepts. Such examples do not allow students to make decisions, such as, selecting appropriate instruments, to identify and manipulate variables, to accumulate appropriate results or to interpret and communicate their findings. In addition, for some such activities described in the texts, as in Fig. 2, the 'correct' results of the experiment were shown asserting that neither development of some of the procedural skills of investigation nor an appreciation of the nature of science was a key objective.

Some communicative and interpretative activities requiring students to construct a graph from given data appeared in the texts reviewed. However, in none of these was there an opportunity for them to collect and present their own experimental information. Indeed, sometimes the texts specified that students should copy the graph, or locate points after copying the given axes. Such activities do not encourage understanding of the principles of graph construction or of the conceptual focus of the experiment to allow pupils to talk knowledgeably about the relationships between the variables under investigation. Furthermore, there were many cases that suggested that the textbook authors had not themselves tried out the activities. In an 'Accelerated Motion Task', for instance, students were required to note and record, at 1-second interval, the position of a rolling ball released from the top of a steeply inclined plane.

Assessment Procedures

The study analyzed the Physics and Chemistry papers of the Ethiopian School Leaving Certificate Examination (ESLCE) along with the internal examination papers of the four schools for both subjects at Grades 10 and 11 over the five years 1991 to 1995 inclusive. There was no explicit, published list of assessment objectives or a grid indicating the balance of distribution of marks across curriculum objectives. This meant that there was no guidance available to teachers about the balance of objectives to be tested. There was no published basis for the analysis undertaken for the study; hence the same framework as used to analyze the curriculum guides and texts was adopted. All the internal schools examination papers were modeled strictly on the ESLCE papers and the analysis unsurprisingly revealed the same pattern.

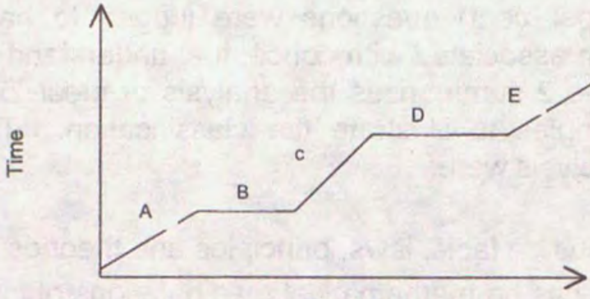
The examination papers were scrutinized to determine the coverage of the range of assessment objectives including questions that assess, for example, ability to draw graphs, some elements of planning or interpretation of data. Neither the ESLCE nor the school science examinations included a practical paper.

A total of 625 ESLCE questions (225 physics and 400 chemistry) were analyzed. The examination papers always included 45 questions for physics and 80 questions for chemistry per exam paper. All the questions were multiple-choice. Physics items had four distracters with five for chemistry. Of the 625 questions, there were no examples of

- practice-oriented questions in the context of an experiment;
- problems to test procedural knowledge such as when, how or what to measure, for instance; and
- problems to test applications to arrive at a solution.

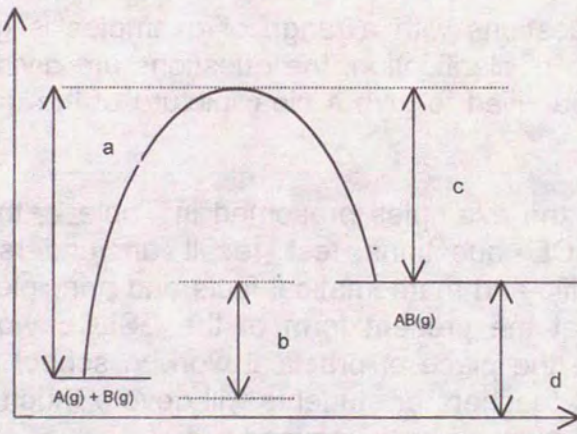
There were a few questions, 6 (less than 1 per cent) for physics and 26 (just over 4 per cent) for chemistry, requiring students to interpret data or other information. Two of these questions are presented in Fig. 3.

3.1 Energy is supplied at a constant rate to a fixed mass of a pure substance. The resulting variation of temperature with time is shown in the graph. Assuming that all the supplied energy stays in the substance, which one of the following is the best answer?



A. The state of the substance in the parts of the graph marked A, C and E are most probably solid, liquid and gas respectively.
B. B and D most probably correspond to the physical processes of melting and evaporation.
C. The internal energy of the system increases as we go from A to E.
D. All of the above.

3.2 Use the following figure to answer questions 189 to 191 about the reaction A(g)+B(g) → AB(g).



3.21 Which portion of the plot indicates the value of heat of reaction/
A. a **B.** b **C.** c **D.** d **E.** None of the above

3.22 The reaction as indicated by the energy diagram
A. is endothermic **B.** is exothermic
C. has forward activation energy less than reverse activation energy
D. has temperature dependent activation energy
E. all of the above

Fig. 3: A sample of ESLCE questions associated with data/information interpretation

The remaining 593 (95 per cent) questions were judged to have simple recall of information associated with conceptual understanding as their main focus. Table 2 summarizes the analysis of these 593 test items, showing examples to illustrate the classification. The classes derived for the analysis were:

- items with the main focus on facts, laws, principles and theories;
- items where the focus was on mathematical manipulations of laws and principles;
- items with a focus on relationships between theories and phenomena; and
- items which required very specific recall of information about events, conventions, terminology, dates, names, formulae and units.

A sample of these questions with a range of examples is given in Table 2. For the sake of clarification, the questions are divided into sub-categories and quantified to give a clear picture of the nature of the ESLCE.

As can be seen from the examples presented in Table 2, the large majority of the ESLCE questions test recall an understanding associated with scientific and mathematical facts and principles. The implication here is that the present form of the ESLCE would not promote and enhance the place of practical work in school science since it is unlikely that teachers or students will devote much time to curriculum objectives which are not examined.

The results of the school examination papers yielded similar results. In line with the ESLCE, school examinations do not sample the full range of curriculum objectives. The school examinations largely tested recall of information, knowledge associated with conceptual understanding and they contained some data response items. The only real difference between the ESLCE and school examinations was shown in the type of questions in use. The school examination, in addition to multiple-choice, included matching pairs, closed-exercise type questions and true/false test items. Such written assessment practice is common in the other secondary schools in Ethiopia.

Table 2: A classification of Physics and Chemistry ESLCE questions, 1991-5

	Questions that test knowledge associated with			
	Facts, laws, principles, theories	Mathematical laws and principles	Relations between theories and phenomena	Specific information; events, conventions, terminology, dates, names, formula, units
Physics All questions n=219(100%)	47(21.5%) Which of the following is not true about Newton's 3rd Law? A Two objects exert equal and opposite forces on each other when in contact B If two objects exert equal and opposite forces on each other, they may not have equal and opposite accelerations C The total force acting on is zero because action and reaction pairs re equal and opposite D. Two objects may exert equal and opposite forces even when they are not in contact	147(67.1%) A car travelling at a speed of 40m/s is accelerated uniformly to a speed of 60m/s in 2 seconds. How far does the car travel during this time? A 60m B 100m C 80m D 200m (1995 Q. No. 1) What is the buoyant force on a 5 kg solid object (density = 10^4 kg/m^2) when immersed in a fluid having a density of 5 x 10 kg/m^3? A 25N B 10N C 20N D 25 N (1994, Q. No. 16)	10(4.6%) When an electron is projected horizontally into a region where there is a uniform magnetic field pointing vertically upward, the electron moves along a circular path A. in a clockwise direction B. Whose radius is directly proportional to the charge of the electron C. in the counter clockwise direction D. Whose radius is inversely proportional to the mass of the electron (1995, Q. No. 38)	15(6.8%) One of the following prefix that may be used to indicate sub-multiples of measuring units, which one is arranged in increasing order? A. nano, pico-, micro-, milli- B. mill-, micro-, nano-, pico- C. micro-, milli-, nano-, pico- D. pico-, nano-, micro-, milli-(1991, Q. No. 1) One can store hot tea or coffee in a thermos flask for 24 hours without any appreciable change in temperature, this is mainly because one of the following heat transfer methods has been discouraged in the construction of the flask A. conduction B. radiation B. convection D. evaporation (1992, Q. No. 18).

Table 2 continued

	Questions that test knowledge associated with			
	Facts, laws, principles, theories	Mathematical laws and principles	Relations between theories and phenomena	Specific information; events, conventions, terminology, dates, names, formula, units
Chemistry All questions n=374(100%)	133 (35.6%)	130 (34.%)	14(3.7%)	97(26%)
	In 19 g of water there are 2 g of H and 16 g of O. The law which governs this statements is: **A.** conservation of mass **B.** definite proportions **C.** multiple proportions **D.** Avogadro's law **E.** None of the above (1994, Q. No. 1992)	Calculate the mass of potassium permanganate needed to prepare 250 ml of a 0.038M $Kmno_4$. (At. Wt. K = 39, Mn = 55, O = 16) **A.** 1.5g **B.** 2.6g **C.** 3.2g **D.** 4.6g **E.** 5.7g (1991, Q. No. 139)	Two flasks of equal volume are filled with different gases, X and Y, at the same temperature and pressure. Which one of the following is true about X and Y. **A.** The molecular weight of X must be the same as that of Y. **B.** If X is heavier than Y, it will be travelling faster **C.** The number of molecules of X and Y are the same. **D.** The molecular weight of Y is bigger than that of X. **E.** The partial pressure of X is bigger than that of Y. (1995, Q. No. 191)	The charge of the electron was determined by A. Thomson B. Milikian C. Rutherford D. Dalton E. Chadwick (1992, Q. No. 123)

Results and Discussion: The Implemented Curriculum

Eighty lessons were observed in the four sample schools. On only one occasion was practical activity observed and this fell into the category of demonstration by the teacher and pupils were never observed in 'hands-on' practical activity. This rendered redundant the need to categorize the types of practical teaching observed. However, using the FIAC based schedule described earlier, it is interesting to illustrate three typical lessons. This gives a picture of the nature of the transactions of the typical Ethiopian secondary science lesson. Table 3 summarizes these lessons indicating the topic, grade level, recommended instructional guidelines, actual classroom practice observed, and comments on the degree of match between policy and practice.

With regard to practical work the curriculum objectives as intended were not implemented at classroom level. All kinds of practical activity, including active participation beyond listening, writing or occasionally answering questions were simply absent. The only practical activity observed was a teacher demonstrating the attractive and repulsive forces of magnets. Although this attempt can be appreciated in the light of the overall absence of practical work, it did not provide an opportunity for students to test the polarity of bar magnet and plot magnetic fields for themselves as recommended by the curriculum guidelines. The remaining science lessons were entirely didactic, the methods of instruction being largely verbal, designed exclusively to promote learning by rote.

In the following examples, three 'snap shot' verbatim accounts of teacher-student interactions are given. The purpose of their inclusion is to illustrate the style of teaching commonly encountered in science lessons.

Interaction example 1

Topic: *Newton's second law of motion* (Grade 11 Physics text)
For this topic the text suggests an activity to be performed by teacher and students to prove Newton's second law of motion – the relation between force and acceleration. The necessary apparatus and procedural instructions are suggested in the text. No practical activity was observed. Instead the following interaction took place:

Teacher (writing on the chalkboard):

Who can tell me (interpret this relation) $\vec{F}_{1,2} = \vec{F}_{2,1}$.

Student 1 (recounting previous lesson): "Well, $ball_1$ and $ball_2$ collide, $ball_1$ accelerates.

Teacher (with ironic tone): 'Oh ... Jesus! ... Oh ... No!... is there any one who can give me a better (correct) answer?'

No student response

Teacher (answers his own question almost without pause):

When two billiard balls (m_1 and m_2) collide head-on, m_1 exerts a force $F_{1,2}$ on m_2 and m_2 exerts a for $F_{2,1}$ on m_1. These forces are equal but opposite.

Thus $\vec{F}_{1,2} = -\vec{F}_{2,1}$.

Table 3: Classroom Transactions Observed

Topic	Instructional Strategies recommended in the curriculum guidelines	Classroom practice to implement guidelines	Comments
Lesson 1 Electricity and Magnetism Questions. (Grade 10 Physics)	Practical activities: - determining the magnetic poles of a magnet and the forces between magnets and other substances - Testing the polarity of a magnet and other substances Experiments on suspension of magnet, magnetic field and law of magnetism can be done by the teacher, but students should be involved. Students can be asked to observe, describe and explain the process and define the result of the experiments. **(extracts from curriculum guide for Grade 10 Physics: p. 8)**	Teacher lectured at length about magnetic properties and demonstrated to the whole class the attractive and repulsive forces between like and unlike poles of magnets using 2 smaller magnets.	Students sat quietly listening, wrote notes when instructed, answered a few oral questions. No students tested the polarity of a magnet or plotted a magnetic field for a bar magnet as recommended by the curriculum guidelines. Neither the teacher nor the class plotted a magnetic field.
Lesson 2 Inorganic compounds (Grade 11 Chemistry)	In this unit, teacher can use a variety of teaching methods like discussion, demonstration and inquiry method depending on the situation. Some of the activities can be performed by students divided into groups (e.g effects of inorganic compounds on indicators)	Teacher described the classification of inorganic compounds (i.e. oxides, acids, bases, salts). He then described the types of each of the compounds. For example, oxides into acidic, basic, amphoteric, neutral	Students sat quietly listening, wrote notes when instructed, answered a few oral questions. No teacher demonstration,

Table 3: continued

	(Extracts from curriculum guide for Grade 11 Chemistry p. 34-35)	Peroxide. In the subsequent lessons, he lectured about the preparation of the compounds and the test for acidic, basic and other oxides saying acid turns blue litmus red, base turns red litmus blue etc.	Student group activity or discussion were observed as recommended by curriculum guidelines.
Lesson 3 Exothermic and Endothermic Reactions (Grade 10 Chemistry)	Practical activities: - burning of magnesium - reaction of magnesium with a dilute acid The activities should be demonstrated by the teacher. During demonstration changes in energy (exothermic and endothermic reactions) must be emphasized) The students must notice that heat is needed to start the reaction between magnesium and oxygen, while the reaction between magnesium and dilute hydrochloric acid does not need heat energy. **(extracts from curriculum guide for Grade 11 Chemistry, p. 51)**	Teacher described changes in energy in chemical changes. He explained that the chemical reaction which absorbs heat energy is called an endothermic reaction, while a chemical reaction which releases heat energy is called an endothermic reaction, while a chemical reaction which releases heat energy is called an exothermic reaction. Then using symbols, he summarized that: Let E_p = Energy of the product E_r = Energy of reactant If $E_p < E_r$, heat is given out, the reaction is exothermic If $E_p > E_r$, heat is absorbed, the reaction is endothermic	Students sat quietly listening, wrote notes when instructed, answered a few oral questions. No teacher demonstration took place and students were given no opportunity to observe the energy changes during the formation of magnesium oxide and the reaction of magnesium with dilute acid as recommended by curriculum guidelines.

Interaction example 2

Topic: Energy of Reaction (Grade 11 Chemistry text)

For this topic, which is also shown as lesson three in Table 3, an exothermic reaction (burning charcoal in pure oxygen) and an endothermic reaction (reduction of carbon dioxide) are described in the textbooks with suggestions for activities. No practical work was conducted in the lessons observed. The lesson was dominated by lecture and a question-and-answer session at the end of the lesson:

> Teacher: During Endothermic reactions energy is ...
> Some students (together): 'Released'
> Other students (together): 'Absorbed'
> Teacher (without comment on the different views): What about during exothermic reactions 'Energy is ...'
> Few students (together with hesitation): 'Released?'
> Teacher was silent.

Interaction Example 3

Topic: Periodic Classification of Elements (Grade 10 Chemistry text)

> Teacher: 'Atomic number is the number of ...?'
> Whole class (together after slight hesitation): 'Protons'
> Teacher: 'Atomic weight is the number of ... and ...?'
> Whole class (together with hesitation): Protons and neutrons
> Teacher: 'What is the valency of C in C_2H_4?'
> Student 1: 2
> Student 2: 5
> Student 3: 4
> Teacher (without comment on the responses): 'Neon neither loses nor gains electron. Therefore, what should be its valency?'
> Student 1: 2

Student 2: 1
Student 3: 8

Again no summarizing comment from the teacher.

The major form of interaction within the classroom was for the teacher to lecture and the students to listen silently. Variety was provided by teachers asking closed questions with students giving answers. In answering the question, students were required to provide precise answers to correspond with what the teacher was thinking with little or no latitude allowed. On many occasions, students were seen searching through their books to find the 'correct' answers or, more often, to answer the questions by guessing. Students preferred to guess, answering without understanding, than not to respond. Teachers rarely probed to investigate students' thinking following an incomplete or incorrect response. Instead, they passed on to another student until the correct answer, as written in the text or designated by them, was provided.

The above practice was also evident in the teacher-training colleges (Bekalo and Welford, 1999). No practical activity was observed in any of the 20 methodology lessons visited. Although some of the other 20 academic lessons observed incorporated routine laboratory activities and provided first-hand experience, the opportunity was seldom taken to develop trainees' understanding of the purposes of a wide range of practical work available, the complexities of instruction and/or skills of implementation and assessment. In addition, the curriculum materials and classroom practice of the two dimensions of academic and pedagogical courses are not compatible with either the school curriculum or the realities of a typical classroom interaction. The main feature of classroom transactions revolves around the transfer of factual information through chalk and talk and the confirmation of taught concepts through routines--guided experiment approaches. Perhaps this is because the teacher educators themselves did not have the necessary expertise to organize, carry out and evaluate practice-oriented courses. Whatever the situation, it is difficult not to accept the view that the predominantly chalk and talk approach persistently employed by teacher-trainers inevitably affected the practice of teachers in schools, especially in the area of practical work when there are conducive classroom settings and reasonable resources. Sometimes in schools and invariably in the teacher colleges there were classroom settings and resource levels conducive to practical activity, yet teachers were never observed attempting to conduct practical work.

In general, practical activity was conspicuous by its absence. The emphasis on rote learning and correct-answer responses suggested that an active engagement in the process of concept development was not expected in science lessons. Many science lessons thus did not demand the cognitive knowledge and understanding prescribed in the policy and curriculum guide documents.

Reflection

Despite policy statements promoting active approaches to learning, the reality of the science teaching was very different from the intended curricula with regard to practical work. There is little coherence within the intended curriculum between general policy objectives, curriculum materials in the form of the textbooks and the subsequent examinations. Consequently, it is not surprising perhaps that there is little match between the intended and the implemented curriculum.

No student practical work as defined for this study was observed to be carried out by students and only very rarely did teacher demonstration take place. This can be described as a symptom of the major gap between the position held by the education officials and curriculum planners who provide curriculum, and curriculum implemented in classroom practice.

This situation, however, is not unique to Ethiopia. Other studies in many African countries have reached similar conclusions that the relationship between the official and transacted curricula is characterized by many forms of mismatch such as those discussed above (Yager, 1984; Jansen, 1989; Olorundare, 1990; Towse and Amanuah-Mensha, 1994; Benschop *et al.*, 1996: Stoll *et al.*, 1996). The failure to promote the intended practical approach in Ethiopia can be attributed to a complexity of factors which act upon the education system and inevitably affect the quality of science teaching and learning. The factors include limited awareness and understanding on the part of science educators about the role and purposes of a wide range of practical work in teaching and learning science, problems of curriculum development and implementation, assessment procedures and practice, teacher education, and poor physical resources (Bekalo, 1997; Bekalo and Welford, 1999).

Taking the latter of these first, and despite the acuteness of such problems in Ethiopian schools, the extensive classroom observations of this study would suggest that lack of equipment and resources is not always the reason that discourages teachers to use practical work. One of the sample schools and both the teacher-training colleges visited were reasonably resourced and had fewer than 20 students per class. Yet the trainers and schoolteachers were never observed attempting to conduct practical work of any kind. Paradoxically, several of the teachers in that school, described as normal, the crowded urban school classes with more than 60 students – which they had themselves experienced as students – and stated that they were not motivated by the relatively quiet atmosphere of a small class. When asked to elaborate this point, they did not know how to organize small classes to their advantage and could not suggest practical approaches that they might use (Bekalo and Welford, 1999).

Classrooms are complex and variable places, but it would appear that the teachers observed were not flexible or knowledgeable enough to exploit favourable conditions and thus provide children with recommended practical experiences. However, inappropriate teacher education, lack of on-going support by educational authorities such as the provision of professional courses or subject advisors, or other factors mentioned above, were mentioned by some of the educators interviewed as inhibiting the development of practical science education in Ethiopia (Bekalo, 1997).

Reflecting on the compatibility of teacher education and the school curriculum, a teacher-trainer said:

> Most of us here are pure physics, chemistry, biology graduates. .... We took a few educational methodology courses at university, but that is not enough and we can't say we are educators. Because of our background, our college courses (which we teach) are highly influenced by the university course we brought with us. You can compare the contents yourself. On the contrary, we do not relate the content to the school curriculum and I have never even seen any school curriculum materials (and I have been working here for years). I think there is a clash between what we teach and the objective of the college to train teachers for schools.

A school teacher said:

> In college we didn't refer to secondary science textbooks and we were not taught how to use them, particularly the experimental activities. In fact, we did some experiments in college, but what we did was what our tutor told us to do. When we came to schools there was no guidance from tutors and it was difficult to start the experiment from scratch on our own. If we were taught how to start and finish the experiment we would not have such a problem.

Reflecting on examinations and a lengthy syllabus, one school principal Said:

> If you want the truth, I encourage teachers to prepare students for school leaving examinations (ESLCE) from Grade 9 (so they) can understand the styles and tricks of the exam questions and will be able to pass. If more students pass in ESLCE the school will be recognized by the Ministry and parents and every body. Last year my secondary school succeeded in passing the highest number of students in ESLCE and the name is at the top in the Ministry of Education. Besides, teachers can't finish the syllabus in the given time, even through theoretical method let alone experiment. There is always a rush to finish the textbook but we manage it by giving makeup class in the opposite shift.

Faced with such pressures, many educators, particularly teachers, appeared overwhelmed. Further, they were embittered by what they saw as poor levels of payment and they did the absolute minimum during their time at school and, as in other parts of Africa, and devoted their energies to other pursuits to earn money (Knamiller *et al.*, 1995). When pressed teachers attributed the poor quality of science education and the responsibility for improvement to government and did not accept any part of the responsibility even for what went on in their classrooms.

In spite of such gloomy findings and analysis of their causes, there are reasons to be optimistic about the future development of more practical approaches to science teaching in Ethiopia. In recent years (post-1991) there has been a fresh growth of awareness among those concerned that the structure and the system of education is due for change and improvement. The moves for change and improvement, including the establishment of the new Education Policy and Sector Strategy (EMPDA, 1994a and b) and the National Organisation for Examinations in 1997, have been followed by an increase in teachers' salaries. It is in this current climate in Ethiopia that the future status of practical science education lies.

Like the present regime, the previous socialist and imperial governments had educational policies that stated science education was to be taught, at least partially, as a process of enquiry (e.g. MOE, 1972; 1980/4/6). However, science educators have not been trained to do the relatively sophisticated job of implementing the stated education policy. Agencies involved in the reform effort as advisory bodies to the Ministry of Education (ESDP, 1997/8), reported a lack of skilled educators to translate the policy into action. Few of those interviewed – science teachers, teacher educators, curriculum developers and others – had a coherent understanding of what practical activity encompassed. There is a desperate need for training and an on-going support from colleagues and consultants in order to fully implement the new policy intention and approach. The future development of a practice oriented science education lies not only in the reform of the policy and curricula materials, but also in the competence of all those involved in teaching science.

Reform of the new secondary science curriculum needs to go beyond writing policy statements and rewriting associated curriculum materials. In the light of the current receptive political and educational climate, the results of the study also call for a major review of how new approaches to the implementation of science education in schools might proceed.

Concluding Remarks

To be successful in translating into action the teaching and learning activities prescribed by the Ethiopian secondary science curriculum, there is a need for all involved to share and disseminate a common perspective on what is involved in practical work. Training is needed to develop relevant pedagogy for teachers. A close match between curriculum and assessment objectives has to be articulated and operationalized. All this has to be done with the full knowledge of what can be realistically accomplished in Ethiopian classroom given affordable levels of equipment. The current curriculum review needs to ensure that the rhetoric of policy is matched by the teaching and learning activities in the curriculum and assessment materials, and then by practice in classrooms, giving value to all domains of science activity.

If it is the wish of the nation to pursue educational policies directed at making secondary science education practical and relevant, policy should be tied to implementation appropriate to the Ethiopian context. Hence, it is not only desirable to have a fundamental shift in the educators' conceptions of the scope of practical science, but it is also necessary to have an understanding that practical science education can be context bound (Archenold *et al.*, 1988; Lock, 1995/8). This means here that students need to experience practical activity in a wide variety of settings, including everyday contexts, in order to generalize their skills. Most educational institutions are staffed with educators with a limited experience of practical work and hence a relatively unarticulated understanding of the nature of science. Thus, improvement of trainers' own professional skills should be given serious consideration within the reform of the education system and the science curriculum. In other words, as suggested by various science curriculum reforms, practitioner educators need to be fully conversant with and convinced about policy and curricula intention (e.g., Fullan, 1991; AAAS, 1993; Donnelly *et al.*, 1993 Weiss, 1995; Donnelly *et al.*, 1996). For this to be achieved, those charged with developing the reforms should look carefully at the existing lack of coherence within the components of the intended curriculum and the mismatch between the intended and implemented curriculum exposed by this study. To assist the process of reform, the following recommendations might be made:

- **Educational Policy Statements**

  The previous policy statements have advocated cognitive, psychomotor and affective objectives for teaching science, but they lack sufficient internal coherence and consistency across curriculum documentation to aid the implementation of the objectives. It is widely agreed that meaningful science education, for both future scientists and scientifically literate citizens, involves learning about the body of scientific knowledge and the method or processes by which that knowledge is generated (Miller, 1983; Black, 1993; Harlen 1993; Millar *et al.*, 1995). Current and future policy statements should provide coherent definitions, goals and guidelines working to common meanings in all associated curriculum materials (textbooks and examination procedures) if objectives are to be fully understood and translated into action.

- **Curriculum Development**

A reformed curriculum should not be overcrowded and the syllabus load should be well thought-out and planned as suggested by many educators interviewed. The theoretical content of the present secondary science courses may need to be sharply pruned, while retaining the intellectual rigour demanded of pupils. The identification of concepts in science to which all children need to be introduced, how this relates to their lives, the appropriateness of what is to be studied according to their age and ability, should be addressed. With regard to practical work, the range of practical activities to be introduced should have very clear particular purposes to promote learning. The time and resources available are necessarily limited, thus materials and approaches should be included only where they can be clearly justified. This means there may be a need to limit the number of a variety of practical activities with clear objectives and mandates for teachers and students to carry them out.

Such curriculum development should include significant input from experienced teachers and teacher-trainers as well as examiners (which has not been the case so far) to ensure a match between curriculum objectives, assessment objectives and the realities of classrooms. Inevitably, this approach requires time and finance for consultation and for the development of human and material resources, but ultimately it will permit durable changes to be effected. Cost-effective mechanisms for coordinated curriculum development and implementation beyond the national levels, such as at provincial, district and zone levels, will need to be sought to ensure full implementation.

- **Assessment**

Notwithstanding the present form of written examinations used almost exclusively for selection purposes, the curriculum objectives in terms of practical work are unlikely to be achieved in the absence of practical elements in the assessment procedures. As Monk *et.al* (1993) point out, teachers faced with a content dominated syllabus and a predominantly recall-type examination may be both brave and foolish to change their ways of instruction. If the curriculum is to achieve the desired effect, the current examination procedures would have to be substantially modified, and greater emphasis placed than has hitherto been the case on testing practical science capability. This may additionally involve the development of systems of internal assessment carried out by teachers, being moderated and standardized by the newly established examination board.

- **Teacher Education**

The present teacher education progaramme suffers from serious limitations. Teachers are not being prepared to teach any kind of practical work. At present the two dimensions of academic and pedagogical content are not given comparable credit or attention. Trainees are not taught how to plan and carry out a wide range of practical work and are not exposed to thinking about the complexities of practical instruction and assessment in school contexts (Bekalo and Welford, 1999). An alternative, if less charitable explanation, is that the teacher trainers themselves do not have the necessary practical skills to organize, carry out and evaluate investigations in science, let alone to teach teachers to carry out practical science investigations. It is not surprising therefore that teachers trained under such circumstances were not observed attempting practical work in schools even when there were conductive classroom settings and reasonable resources. They did not know how to!

The teacher education program could embody and build upon what Shulman (1986, 1987) refers to as content knowledge, pedagogical content knowledge and pedagogical knowledge. Current programme reviewers may consider easing the curriculum load in teacher-training establishments and adjusting weightings to value both the academic subject and pedagogical components of teacher development. This may serve to alleviate the lack of motivation and interest shown by tutors and trainees alike in low-credit pedagogical courses. Furthermore, the pre-service training programme would do well to reflect the school curriculum and what student-teachers may be called upon to do on their appointment to school, especially in the area of practical work in science. In-service programmes should likewise expose teachers who are already in schools to relevant new approaches and techniques in order to carry out reforms in the classroom. In order to do this teacher-training institutions might need to review and develop their staff specialisms and then their programme, so that new school teachers may be provided with a firm foundation on how to train pupils in experimentation and how to organize their classroom to develop active approaches to learning.

- **Appropriate Use of Human and Material Resources**

The absence of links between educational institutions has inhibited the sharing of understanding of practical work thus reducing the effective use of existing human and physical resources. Closer liaison between educational institutions from schools to teacher-training institutes, from the curriculum development unit to the examination unit and the Ministry, might increase the sense of involvement and commitment of all involved. A possible mechanism effective in many countries is a professional association to promote communication between the various stakeholders. This could lead to an efficient sharing of perspective in the common development of a coherent practical science education which includes good use of such local resources as the environment, indigenous technology and locally available low-or no-cost equipment. Such approaches are in danger of being seen as 'second class' to be as effective in promoting learning as the high-cost imported apparatus. Current educational programme reviewers may wish to consider works of several studies that indicate that, if well thought out and planned, the use of local resources has achieved enviable results elsewhere. Contextualizing particular investigations and providing opportunities for pupils to extend their awareness of everyday phenomena in their surroundings, has contributed to the development of skills of manipulation, observation, experimenting and predicting (see, for example, Swift, 1983, 1992; Knamiller, 1984a and b, 1989; Yakubu, 1992/4; Towse, 1997; Bekele *et al.*, 1990; Macdonald, 1980; Macdonald and Rogan, 1990; Zim-sci, 1987). Alternative approaches to conventional laboratory work, recently reviewed extensively (IJSE, 1998), could result in the positive effect of promoting meaningful learning in science, particularly in countries such as Ethiopia, where the lack of physical resource is a critical factor.

This paper has been able to provide a picture of the absence of practical work in secondary science in Ethiopia and exposed the mismatch between the intended and implemented curriculum. It is hoped, however, that it has set the context for future work to be carried out in order to develop the human and material resources required to promote and implement a science curriculum that includes practical activity. It should be stressed that the new education policy reform, which promises more practical work in science, must be comprehensive, from objectives to content and methodology, from classroom practice to assessment. Fullan (1991) supported by a recent study in Southern Africa (Benschop *et al.*, 1996; Stoll *et al.*, 1996) presents a comprehensive overview of the complexity and demands of an educational reform for all stakeholders involved in educational development, and emphasizes the importance of simultaneously addressing the different factors discussed above in the pursuit of educational excellence. Failure to consider and reform every facet discussed in this paper could retard the whole system and prevent the realization of the stated ideal of a practice-oriented science education. Neglect of the potential sources of the mismatch between the intended and the implemented curriculum has prevented progress in every science curriculum reform to date.

Note

For pragmatic reasons the detailed study was limited to the Physical Sciences. The general impression gained was that the trends noted for the Physical Sciences hold true for the Biological Sciences as well.

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