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Mastery of Science Process Skills and Their Effective Use in the Teaching of Science: An Educology of Science Education in the Nigerian Context

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Abstract

Educology is knowledge about education, and the educology of science education is knowledge about the process of teaching and studying science in some setting, e.g. in schools, colleges and universities.

Part of scientific expertise is having the process skills associated with scientific inquiry. Expertise in science process skills is a basic and integral part of having effective science teaching skills. Such expertise obviously is not innate. One is not born with it.

To become expert, one must receive guidance in the ways of scientific inquiry, and one must conduct extensive guided appropriate practice in the use of the skills of scientific inquiry.

The development of skills in scientific inquiry requires that students of science be provided with appropriate and adequate guidance in their study of science. This guidance is to be found in the instructional programs provided by schools, colleges and universities.

Competent, adequate and appropriate guidance must meet a number of conditions. These include guidance in practical work which enhances the quality of a teacher's

learning. As Ausubel notes, practical work creates a "discovery-reception continuum" as opposed to a "meaningful rote learning" experience. In short, practical work enhances the quality and extent of scientific understanding achieved by students.

Experiences for school students in their guided study of science should include experiences which promote process skills, such as measuring, observing, classifying and predicting. These skills are critical for the development of a worthwhile and fruitful understanding by students of scientific concepts and propositions. These experiences are also critical for achieving expertise in the meaningful use of scientific procedures for problem solving and for applying scientific understanding to one's own life.

The Nigerian context is one in which science teaching in primary and secondary schools all too often emphasizes rote learning without sufficient meanings and connections being made by students with their ordinary lives. Students often come away from science classes with a memorized set of definitions, but without a scientific attitude, without any appreciable expertise in scientific process skills and without any substantial ability to relate scientific concepts to their day-to-day lives.

This state of affairs needs rectifying, and an obvious place to start is with the education of the teachers themselves (1) in science and (2) in the educology of science education.

Introduction

Ango and Gyuse (1987) have argued that, within the context of Nigerian culture and schools, practical work under the guidance of competent teachers with scientific equipment and procedures are vital aspects of scientific

training. They further have argued that all school science instruction should include practical work as a substantial proportion of the instructional program. The benefits of practical work are many. Practical work turns abstract concepts into concrete experiences. It engenders not only skills which are appropriate for scientific inquiry, but it also inculcates attitudes and conceptual perspectives which are necessary for skilled scientific inquiry. Practical work is especially important for Nigerian children because so many come from backgrounds in which a scientific viewpoint and empirical experimentation are simply not part of their cultural heritage.

Ausubel (1968) supports this view that practical work is extremely valuable in promoting the development of meaning and understanding. He maintains that practical work enhances the quality of a student's learning. In his words, practical work creates a "discovery-reception continuum," as opposed to a "meaningful rote learning" experience. He argues that process skills, such as measuring, observing, classifying and predicting, are crucial for the development of a fruitful understanding of scientific concepts and propositions and for a meaningful use of scientific procedures for problem solving and for applying scientific understanding to one's own life.

It is appropriate to conceive of teaching as not only giving guidance and providing counselling, but also as skillfully constructing situations in which students may engage in guided study with a view to achieving intended learning outcomes. To this end, Ango and Gyuse (1987) have suggested that teachers should "not do all the telling, discussing and doing" in science classrooms. They advocate that school teachers not only initiate action and demonstrate skills, but also provide appropriate practical

work and experiences for their students. In doing so, teachers need to exercise their creativity and utilize what is available in their environment through improvisations. Within the context of Nigerian schools, this is a necessity because of the scarce instructional materials, equipment and resources available to schools. Addressing the issue of teacher improvisation, Balogun (1982) advocates that Nigerian school teachers look in their environment and local setting for look alike and substitute materials. Others concur, e.g. Olademeji (1978), Ango (1982) and Oludotun (1986).

Process Skills Which Are Important in the Process of Teaching and Studying Science

There are many process skills encompassed in the conduct of scientific inquiry. It is a complicated business, and it is not appropriate to teach all process skills at once or to teach all of them at all age levels of students.

The concept of the spiral curriculum provides an appropriate guide for the teaching and studying of process skills in science. Appropriate selections of science process skills can be taught and studied in the early years of primary school. The young students can be given the opportunity to to observe, handle things and explore the environment. The basic learning which pupils achieve from these initial experiences can be used as a basis for building a more extensive understanding of science process skills in the later years of primary school and on into secondary school.

Within Nigerian schools, one of the major deficiencies which sadly arises out of the teaching and studying of science is that students develop very limited understanding of scientific concepts. For example, they can write a definition for osmosis, but not associate any meaning with

the definition. They can say and write the words, "An acid is a proton donor," but they attach no meaning to the words.

For the teaching and studying of science to be of substantial value, the students must be able to apply scientific concepts, procedures and attitudes to their wider life. The value of learning science is greatly enhanced when the students are lead into an extensive understanding and a practical conception of how scientific concepts and principles apply to themselves personally, to their families, their communities and their nation. A restricted and narrow understanding of science without expertise in the associated scientific skills is an understanding with very limited value.

Lamentably, in Nigerian schools, sometimes the teacher is the major impediment to the process of developing scientific skills. Teachers sometimes simply lack expertise in the science process skills themselves because of inadequate and inappropriate training. In their preparation to become professional school teachers, their guided studies of science have been deficient. Also, their guided studies of the educology of science education, i.e. knowledge about the teaching and studying of science, have been inadequate.

Among the science process skills which should be engendered in the teaching and studying of science are those of measuring, observing, classifying, inferring, predicting, communicating, interpreting data, making operational definitions, posing questions, hypothesizing, experimenting and formulating models. School teachers need to be expert in these processes, and they also need to be expert in the teaching of these processes.

From range of process skills associated with scientific inquiry, some of the skills can be rated as being the very basic ones. Students should be introduced to these skills early in their school experience because so much of their

success in subsequent guided studies requires a sound understanding and appropriate use of these skills. This basic set includes the skills of observing, measuring, classifying, inferring and communicating.

Reports of Educological Research Findings on Nigerian Teachers' Mastery and Effective Use of Science Process Skills

For some years, Ango and a number of post graduate students at the University of Jos in Plateau State have been conducting educological research aimed at determining the degree to which school teachers in Nigeria have mastered and can use scientific process skills. This research has been conducted on the assumption that mastery of scientific process skills by science teachers is a prerequsite for science teachers to be able to foster those same skills in their students. A second assumption is that this expertise alone is not enough to do the job adequately. Teachers must also have expertise in the educology of science education. That is, they must also be able to make appropriate instructional provisions for their students to engage in effective guided studies of scientific concepts, propositions and procedures.

The Nigerian National Policy on Education (1981:5) properly places a significant emphasis on the importance of students acquiring skills. The objective is stated as follows:

> The acquisition of appropriate skills, abilities and competencies both mental and physical as equipment for the individual to live in and contribute to the development of his [sic] society.

The importance of the role of process skills in the teaching and studying of science is widely acknowledged by experts in the field. Brown and Jegede (1982), for example, argue for the value of learning process skills in order to develop expertise in problem solving. Of necessity,

school teachers necessarily play a crucial role in assisting students to acquire scientific process skills. There is a prima facie case that teachers need to acquire the skills of science in order for them to be in a position to foster the same understanding of those skills in their students. This is but one condition for success. The other is that teachers must acquire expertise in the effective teaching of science. They must know both science and the educology of science education.

In order to make it clear what is meant by basic process skills of science, a selection of these skills is explicated as follows.

1. Process Skill: Communicating

Communication is a critical aspect of scientific investigation. Without it, scientific investigation would be pointless. No one, other than the original investigator would be able to know the results or findings of the investigator. Thus, the skill of communication must be included in the early stages of teaching and studying of science. Thoughts, ideas, research findings and all sorts of vital information need to be communicated for awareness, learning, instruction and other purposes. There are many means of doing so, for example, speech, writing, pictures, diagrams, graphs, mathematical formulae, tables and figures. The importance of communication is widely acknowledged by experts in the field, for example,

> Observation and communication ... are two process skills which are absolutely essential if an individual is to relate to the physical world. [AAAS Report, 1965:17]

2. Process Skill: Observation

Observation is another one of the most basic and first used process skills of science. Almost every activity of

science begins with observation. From nature to the test tube and to experiments in the laboratory, observation must be used.

A useful characterization of scientific observation is given by Harlen (1987:183):

> taking information about all things around, using the senses as appropriate and safe; identifying similarities and differences; noticing details and sequence; ordering observations.

Observation alone is not necessarily an accurate and reliable activity for gathering data. Observers often "miss seemingly obvious things" and "invent quite false observations." Nevertheless, the skill is valuable for and crucial to both the process of conducting scientific inquiry and to the process of teaching and studying the ways of science.

Dang (1991: vi), in investigating Nigerian teachers' mastery and use of observation processes in biology teaching, discovered that teachers scored reasonably well on mastery and effective use of the skill (64.6% and 60% respectively). Contrary to expectations, the less qualified teachers showed higher mastery and effective use of the skill. National Certificate of Education (NCE) holders showed the least effectiveness in the use of the skill. The teacher's mastery and effective use of observation were linked with age, qualification (i.e. level of school, college or university attained) and teaching experience. It was found that there was a significant relationship between these three variables and the level which students attained in mastery and use of the skill.

3. Process Skill: Classification

A clear statement of what constitutes the process skill of classification is that of Ndu (1988:7): Classification is the "process of sorting, grouping and arranging on the basis of

similarities and differences."

Classification as a science process skill is important because it contributes to the extent to which students understand, conceptualize and attach meaning to scientific ideas. Classificational keys are important for conceptual organization. They facilitate students' understanding and promote sound conceptual structure by allocating items within a conceptual scheme. Classificational keys also facilitate students' ability to retrieve information from a conceptual scheme (Kahl, Bulletin No. 161, Wisconsin).

To attain competency in the use of classification means that students are able to conceive of order and add meaning to their experience of the world around them (Tokara, 1991:47). Tokara (1991: xi), in addressing the issue of mastery of classifying in Nigerian schools, found a positively significant relationship between student mastery of the skill and mastery by the teacher of the skill. Tokara also found a significant relationship between the teacher's ability to classify and the teacher's academic qualification, but not the gender of the teacher.

4. Process Skill: Manipulating

Conceptions of contemporary best practice of teaching and studying emphasize that students should be involved in the study process through manipulation of equipment and objects and through participation in any scientific activities pertinent to a given situation in effective guided study.

The "child's education" must be based upon "the strategies of inquiry that facilitate the adaptation of knowledge to new demand" (Hurd, 1964). To almost all experts and proponents of best practice

> Good science teaching must be based on observation and experiment. There can be no substitute for these. [UNESCO, 1962: 9]

Pam (1991: vi-vii) conducted an investigation in Nigerian schools of the mastery and effective use of providing opportunities for students to manipulate materials. Pam found a significant positive relationship between teachers' mastery of manipulative skills and academic qualifications. However, no significant relationship was found between the teachers' expertise and gender. Also, no significant relationship was found between teachers' mastery and students' attainment of the skill. Pam concluded that the teachers' effective use of the skill is nonetheless critical to the effective teaching and studying of science.

Ango (1986: 35) notes the importance of practical experiences in science teaching and learning in this way:

> A learner acquires more in a science learning situation when he/she is given the chance to perform certain activities which include, manipulaitng apparatus, classifying data, designing experiments, ... [forming hypotheses] to making inferences and verifying results.

5. Process Skill: Measuring

Learning by students is facilitated by the process in which they are informed with feedback about their solutions to problems. With feedback, they can rework problems, formulate new problems and solve them. One of the main ways in which students receive feedback from their scientific inquiry is through measurement. It is a science process skill which gives students an opportunity to appraise themselves realistically. Adetula (1981:15) states clearly the important role of measuring:--

> Nearly every aspect of contemporary civilization depends on the concept of measurement and its application, ranging from the relatively simple measurements needed for the manufacture of clothing to the highly complex measurements required to send a space craft into orbit.

Measuring involves evaluation, which entails value

judgements. James (1963: 249) defined measurement as a process which involves comparison of an entity with a standard unit of measurement which has been arbitrarily determined.

Timothy (1992: v-vi), conducted an investigation of Nigerian teachers' mastery and effective use of the process skill of measuring in the teaching of integrated science in junior secondary schools. The findings showed an increase of mastery of the skill with the age of the students. It also showed no significant relationship between the teachers' mastery and the students' mastery. Finally, experienced and professionally qualified teachers showed mastery of the skill more than the inexperienced teachers.

6. Process Skills: Questioning

Posing questions is one of the most commonly used process skills of scientific inquiry. It is also part and parcel of everyday classroom teaching and guided study activities. That is, questioning is an important scientific process skill. It is also well established in educology as an important effective teaching skill and an important effective guided study skill.

Whether initiated by teacher, student, or both, posing questions establishes a critical basis for classroom communication. Even if a science classroom is completely devoid (as some Nigerian classrooms sadly are) of apparatus and chemicals for demonstration and experimentation, teachers and students can still ask questions of each other. And the questions constitute an important avenue for teachers and students to make science lessons lively and involving.

A number of educologists have identified the value of teachers posing questions for their students. For example,

Kwatishe (1992: 15), notes that "questions have distinct characteristics, serve various functions and stimulate different kinds of thinking" in students. Rothkopf (1972: 87) maintains that posing questions to students has the effective of improving their learning performance. Andre (1979: 281) argues that when teachers pose questions to students, they give direction to students "to examine instructional material or ... [their] memory of it and to produce some [meaningful] response." Akinmade and Mang (1991: 2) view questions as "a useful stimulus to plan and execute investigations ...." Campbell (1987:15) sees questions as guides which give direction to decision making and action. Martland (1975: 74) argues that one of the important values of teachers posing questions to students is that the questions help students to focus and clarify their thoughts and conceptions.

Jacobsen et al. (1984: 144) provide an appropriate summary of the value of teachers asking questions of students:--

> A cornerstone of any effective teaching technique is classroom questioning. It is a critical skill that can be used with any subject matter area, any grade level, and with any given teacher personality. It promotes involvement, enhances learning, requires little effort, and motivates the students. It promotes a shift from teacher-centred to a student-centred environment.

Kwatishe (1992: xi-xii) investigated teachers' mastery and effective use of the skill of questioning in Nigerian classrooms. A significant relationship was found between teachers' mastery of the skill and their professional academic qualification. This finding implies that for teachers to exhibit the art of questioning they must be trained in the art. That is, it must be included as part of their study of educology, as well as of their study of science. Kwatsihe also found that teachers' competence with the

skill of posing questions had no significant relationship with their years of teaching experience or with their gender. On the other hand, it was found that there was an indication of a general influence of the teacher's skill upon the students' performance, i.e. attainment of intended learning outcomes.

Not all types of questions are always useful in every instance of teaching and guided study. Types of questions should match the level of understanding and reasoning ability of the students. In addition, some questions only promote recall of information and rote learning with very limited comprehension of meaning on the part of the students. Other questions, when framed properly, promote higher levels of reasoning, thinking and analysis. Within the teaching and guided study of science in schools, teachers need to achieve a balance of questions which call for both simple recall and higher orders of reasoning and problem solving. To be effective in the task of promoting extensive and useful scientific understanding, attitudes and skills, school science teachers necessarily must develop a range of skills in relation to posing appropriate questions to students. As Farrant has stated, the appropriate use of questions by teachers within the classroom setting is

> A highly complex skill requiring an understanding of people and group psychology as well as a thorough knowledge of what is being taught. [Farrant, 1980:191]

7. Process Skill: Organization

Science is characterized as being systematic because of its organized, special approach to investigation and problem solving. Guruge (1977:5) defines organization as a social process which is designed "to ensure cooperation, participation and intervention of others in the effective achievement of a given determined objective."

The skill of organization as a teaching process which

uses school laboratory experiences for science students is summarized by Soar and Soar (1979: 97-120). They identify three phases of organization, or perhaps they are more properly conceived as three dimensions of classroom organization, i.e.

> ***... getting students involved*****,** controlling disruptive behaviour and regulating students movement
>
> ***Organizing student thinking tasks***. ... Organizing methods by which learning tasks are selected and implemented.
>
> ***Organizing students thinking process.*** ... Cognitive level thinking encouraged in laboratory and the kind of freedom students have to explore ideas.

Soar and Soar are addressing the issue of organization as part of the educology of science education, i.e. as knowledge about a set of teaching skills which are effective in the teaching of science.

Al-Kamu, (1992: vi-vii) conducted an investigation in Nigerian schools of teachers' mastery and their effective use of the skill of organization in the teaching and guided study of biology. It was found that most teachers acknowledged the importance of organization. In the sample, 87.7% of the teachers indicated an awareness of the skill as important and useful in the teaching of biology. No significant relationship was found between of the organizational competence of the biology teachers and their levels of qualification, teaching experience and gender. Al-Kamu compared the frequency of use of the skill by biology teachers with the learning achievement of biology students. It was found that those students who experienced frequent use of organizational skills by their teachers achieved higher levels of achievement in their biology practical test.

8. Process Skill: Experimentation

For Gagne (1963:145), exptertise in scientific inquiry is

the ultimatel objective of science education. His conception of teaching and conducting guided study of science and his conception of scientific inquiry and the nature of science are rooted deeply in the activities and experiments which students under guidance undertake. Scientific inquiry is constituted by

> A set of activities characterized by a problem solving approach in which a newly encountered phenomenon becomes a challenge for thinking. Such thinking begins with a careful set of systematic observations, proceeds to design the measurements required, clearly distinguished between what is observed and what is under ideal circumstances, brilliant leaps, but always testable and draws reasonable conclusions.

Extending on Gagne's conception of appropriate circumstances for the effective teaching and guided study of science, Ausubel (1968) argued that such teaching and studying should lead to the students achieving meaningful learning vs. rote learning. With meaningful learning, students have extensive mastery of a range of useful scientific skills. With rote learning, they are able only to write definitions and lists, but they are not able to solve problems. Obviously the business of teaching and conducting guided study of science should be aimed at achieving meaningful learning.

Choji (1992: vi-vii) conducted an investigation of teachers' mastery and effective use of the skill of experimentation in Nigerian classrooms. It was found that students' experience with apparatus and experiments had a highly significant relationship with their understanding of science and of experimentation as a process of science.

The challenge within Nigeria is that of conducting effective teaching and guided study of science with inadequate or nonexistent resources, such as apparatus, illustrative materials and chemicals.

9. Process Skill: Interpreting Data

Scientific inquiry is empirical in nature. Through observation and experiments, data are gathered. Once collected, the data need interpretation so that meaning and sense can be related to the data. Interpreting and inferring are critically determinant activities of science. Information gathered from scientific investigation usually is not readily useful and meaningful to other scientists and the wider community. Data have to be analyzed and interpreted, and inferences have to be made to produce and extend knowledge which is to have usefulness and meaningful applications for life.

Fom (1991) undertook research on teachers' mastery and effective use of the skill of interpreting data in the teaching and guided study of integrated science in Nigerian schools. It was found that inspite of teachers being aware of the importance of the skill and having a high degree of mastery of the skill themselves, their students indicated that they rarely used the skill. No significant relationship was established between teachers' experience and their expertise in the use of the skill.

The value and the necessity of the skill of interpreting data needs to be given greater prominence. It needs to be given more prominence in the process of teaching and conducting guided study of science in Nigerian schools. It also needs to be given more prominance (1) in the teaching of science in teacher preparation institutions and (2) in the teaching of the educology of science education in teacher preparation institutions.

Conclusion

Process skills of science are basic and critical

components of the process of conducting study of science under the guidance of a teacher. For many years, now, Bloom's taxonomy of educational objectives has received wide recognition, and it has been used in many curriculum design and development projects. Bloom identified three major realms or domains of intended learning outcomes: the cognitive domain of knowledge, the affective domain or attitudes and the psychomotor domain of manipulative skills. These categories have stood the test of time and acceptance by experts, and they provide an excellent conceptual framework for revision of curriculum so that it incorporates the basic scientific process skills.

The sure route to the attainment by school students of mastery of the basic skills of science is through having adequate teachers. The teachers must be experts in two areas. They must be masters of science process skills. They also must be masters of effective teaching practices which optimize the chances of students effectively studying and learning the skills. The process therefore begins in the institutions which prepare candidates for professional school teaching. The expertise of the professional teachers flows on to the school science classrooms. The other part of this process is much needed inservice courses for teachers who are already employed in the schools. It is obvious from recent educological research that teachers already in practice should be given inservice training and retraining in the art of proess skills use and teaching. Brown (1977: 83) appropriately states that

> If inservice teachers are to be held accountable for identifying and teaching a process component of science, then they should be provided with the skills necessary to execute this task.

The obvious avenue of enabling school students to achieve expertise in science process skills is through appropriate preservice preparation and continuous inservice retraining

of science teachers. This requires guided study by teachers of science and of educology of science education.

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