

## Measuring, Assessing and Reporting Skill Performance in Science, Technology and Mathematics Education

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### Abstract

In research, skills are thought of as a quality of performance which does not depend solely upon fundamental innate capacities but must be developed through training, practice and experience. Although the teachers and their pupils often engage in classroom activities, reporting pupils' progress is always biased for the cognitive domain of educational objectives. This omission is blamed on absence of a simple procedure for skill assessment and reporting. This study therefore focused on a skill assessment strategy (SAS) as a diagnostic tool for measuring performance in science, Technology and Mathematics Education (STEME). The study was directed at the population of senior secondary school students in Lagos State Nigeria. The age of these respondents range between twelve(12) and nineteen(19)years. This paper describes one such procedure and shows that it is valid and reliable and can be used at all levels of instruction in science, technology and mathematics. The highlight of the findings showed that students need to attain requisite level of reasoning and acquire relevant skill and positive attitude to succeed in undertaking productive work. It further showed that work in science, technology and mathematics demand both mental and manual skills for a good performance in practical work and problem solving The prospects it offers for diagnosis and prognosis in curriculum and instruction are then discussed and directions indicated for its further development.

### Introduction

Work as basic ability is the means by which man adjusts to life. A person's aptitude and work functions are required necessary antidotes suggesting the appropriate skills he/she can perform or acquired in going through a given work-sample. Skill is defined as an ability to do something expertly and well (Humby, 1974) and connotes the possession of such ability to a pre-specified level of proficiency. In industry, skill refers to the ability to carry out a trade or craft-work involving knowledge, judgment, accuracy and manual deafness usually acquired as a result of long training (Welford, 1951, Adeyemo, 2009). As more practice is ploughed into skill performance, shorter route and smoother ways of time reduces while the quality of skill performance increases with ability to adopt superior organization and management strategies. In the work place, skill is the quality of performance the workers give in exchange for their remuneration. If the skill (or the cluster of skills popularly referred to as aptitudes) given is satisfactory, the worker gets satisfaction and the employer gets satisfactoriness in correspondence. This process, if sustained culminates in promotion, retention and prolonged tenure that leads to productivity (Darwist and Loquist, 1967, Adeyemo 2009).

On retirement from active working life, man's repertoire of skills will no longer be relevant to help him adjust to life. He needs new skills on how to enjoy his leisure and adjust in his new ways of life. This situation is the same for a handicapped person, a widow or indeed any person whose way of life has changed radically. Hence, man's rehabilitation in these contexts requires new skills with special consideration to his aptitudes and work functions. In the case of youth, whose adjustment in the world of work will rest solely on skill developed and used first at school and later at work, the economic, moral and political time of the nation will in time to come depend on it and these will from time to time determine its survival (Darwist and Loquist, 1967, Adeyemo, 2009)

Moreover, the policy on education (Nigeria 2008) recommends activity approach in the delivery of instruction in institutions yet skill measurement, assessment and evaluation have yet to be focused in teacher education and in – service training in science, technology and mathematics in Nigeria.

The above considerations and many more underscore the need to focus skill development and assessment in our teacher education and in – service training programme, more especially in the science – based teaching subjects areas of biology, mathematics, chemistry, physics, integrated science, agricultural science, introductory technology, wood work, metal work, electrical electronics, home economics, clothing and textile etc. One thing that all these subjects have in common is that they involve one form of work or the other hence are all amenable to the same procedure for work function measurement, analysis, assessment and reporting.

### **CONCEPTS OF SKILL**

Until the 1940s, the study of skill was largely confined to industry. People were regarded as skilled when they were able to carry out a trade or activity that involved knowledge, judgment, accuracy and manual dexterity, qualifications usually required as the result of long training (Welford, 1976). In contrast, an unskilled worker was not expected to do anything which could not be learned in a relatively short time. This industrial definition of skill expressed fundamentally in terms of the amount of training and experience required for effective performance has remained essentially the same to the present time. This performance is not exclusively concerned with manual operations, it includes process control, and office as well as attempts to understand the human factors involved in managerial decision making (Welford, 1967, Adeyemo, 2003).

From the on-going therefore, in research works, skill is thought of as a quality of performance which does not depend solely upon a person's fundamental, innate capacities but must be developed through training, practice and experience. Although skill depends essentially on learning, it also includes the concepts of efficiency and economy in performance. Modern concepts of skills stress the flexibility with which a skilled operator reaches a given end on different occasions, varying specific actions according to precise circumstances. However, it must be reiterated that even though basic human capacities are not sufficient to produce skills, they form the necessary basis of their development; skills represent particular ways of using capacities in relation to environmental demands, with human being and external situation together forming a functional system.

Surprisingly, intimately related to classroom activities as the concept of skill may be and necessary as its measurement, assessment and general evaluation may be to the affairs of the school system, little is done about it in teacher education while its records are seldom kept in continuous assessment in schools. Whereas, the National Policy on Education (F.M.E.,2008) enjoins teachers to make instruction concept – centered, activity – based and work – related.

A glaring neglect of policy as it is apparent from situation presented above well illustrates a major way in which standards are often compromised in our schools system. Baiyelo (1999) has shown how changing of policies, rules and regulation often lead to various acts of indiscipline among stake holders in education, in the implementation of the school curriculum.

This fact underlines the need to focus skill assessment in school instruction for the benefit of school and society.

#### **TYPES OF SKILL**

The great advantage of any task is that, if properly undertaken, it helps both to develop and to reinforce skills'. Although, any attempt to catalogue a hierarchy of skills will always have a gap, it should not be a reason why we should not delineate skill areas. Generally types of skill commonly encountered in the school system (i.e. intellectual skills) are as follows:

- Motor skills
- Memory
- General cognitive (verbal, perpetual, quantitative)

These classifications and many more are in relative rather than in absolute term (Adeyemo, 2003). A total of eighteen destructive tests have been developed by McCarthy (1972) covering these intellectual skills which; she organized into six scales. It is to be noted that in each of the above cases, acquisition of skills seems not to increase basic capacities, but to improve the efficiency, economy and effectiveness with which they are used (Welford, 1976)

It should be noted that where the measurement, assessment and evaluation of skills impacts have been alluded to as problems in operating continuous assessment in schools the question of efficiency, economy and effectiveness with which skills are performed have often overlooked. It is probably more for this than other reasons that process skills have been exclusively focused in school instruction whereas it is the skills efficiency, economy and effectiveness that really ensure high productivity in industries (and these include real-life and workplace).

This over simplification of focusing on process skills to the exclusion of other types of skills in school instruction is in part to be held responsible for the gap often easily noticeable between 'work' in schools and 'work' in real life. Hence, effort should be made to investigate this neglect, identify its pervasiveness and types of skill involved and seek how to

propagate and reinforce them as well as sensitize teachers to their measurement, assessment and evaluation in order to bridge the yawning gap between school and real life.

The following operational definitions are necessary and required for clarity. These include:

- i) *Skill*: Skill is thought of as quality of performance which does not depend solely on a person's fundamental innate capacities, but must be developed from time to time through carefully selected and organized opportunities (laboratory activities), practice and experience.  
Welford (1956), opines that both manual and mental skills are involved in any activity in some proportion depending on the complexity of the tasks involved.
- ii) *Skill dimension*: This is defined in terms of such categories of skills requires to get various tasks done and are differentiated by quality and characteristics such as types of preparation needed to undertake work functions and processes, way and means of optimizing processes of work as well as qualities related to ways and means of valuing work processes so undertaken.
- iii) *Task Inventory*: This refers to totality of complete, accurate and precise steps involved in sequential and logically linked practical activities. Any activity contains a finite number of tasks as smallest units of work. The sub-tasks are inclusive, hierarchical and logically arranged.
- iv) *Sat*: This is a table in which skill dimension values are entered against the work sequence of a particular task under analysis
- v) *Skill assessment scale*: This is a scale in which skill dimension values are tabled against the work sequence of any typical operation, indicating quality (strength and weaknesses) of skill and aptitude performance. The scale involved comparing personal skill profile with a standard profile for diagnostic and prognostic purposes.
- vi) *Work*: This is central to man's development and total life adjustment. It provides a situation for satisfying needs. It is the means by which man adjust to life.
- vii) *Skill profile/aptitude*: A skill profile is a cluster of skills which describes a person's work functions and shows what a person is endowed to do. A skill profile may be standard or personal.
- viii) *Scoring protocols*: These are rules for sorting student's behaviour into categories for rating purposes.
- ix) *Standard skill profile*: This is a set of skills to which a full complement of scores is credited as per a valid marking scheme.
- x) *Personal skill profile*: This is the set of skills scored right by a person in a skill test (which map out his / her peculiar qualities, characteristics or aptitude).

### **Statement of Problem.**

The performance of students in the SSCE Examination is not encouraging (both the practical and theory) despite the newness of methodology and content of the physics curriculum. Again, profiles of teachers and students effectiveness are measured largely through perception and are bond to opinions rather than objective data. So far, teachers' preparation in measurement and evaluation is biased for the cognitive demand and school's reporting of students' achievement abundantly reflects this.

To ensure improvement in learning through activity method (in skill-focused method), as recommended by the new policy in education, (FME, 2008), it is better to monitor growth in

skills because it is more pragmatic than to monitor change in perception. It seems therefore, that a focus on skill measurement and evaluation in classroom transaction is bound to be given easier way of monitoring students' achievement in science. Also, studies meant to identify the strength and weaknesses of students in skills performance variables and ultimately check on their effects on students' achievement is yet to be undertaken with sufficiently large sample to permit generalization of outcomes.

### **Skill Dimensions**

Using Baiyelo Paradigm (1999), skills can be organized into ten major dimensions as follows:

- A. Pre-requisite skills: skills related to background knowledge and information.
- B. Preparation and planning skills: knowledge of set – ups, materials, resources, tools and equipment needed to carry out work.
- C. Design skills: rough idea, sketch or diagram of the situation conceptualizing the work to be done
- D. Organization skills: capacity to use orderliness in dealing with work.
- E. Management skills: capacity to use caution and expertise in dealing with work.
- F. Implementation skills: capacity to coordinate work
- G. Operational skills: capacity to carry out work
- H. Analysis skills: ability to relate various components
- I. Evaluation skills: ability to relate various components of work.
- J. Experimental Economy/parsimony skills: ability to uphold a reasonable judgment of cost/ benefit relationship of work undertaken.

According to Adeyemo (2003), it is to be noted that:

1. Each of these dimension has a set of qualities underlined by a set of sub-skills
2. Skill assessment requires distinctive measures in all the factors affecting student achievement viz:
  - i) student effort in:
    - a) Practical work
    - b) Problem – solving
    - c) Motivation
  - ii) teacher's instructional leadership
  - iii) students' learning environment

### **Methods**

The multi-factorial design with pre-selected factors was adopted for this study. Essentially it is a survey of a situation after the event has already taken place (i.e. ex-post factor).

### **POPULATION & SAMPLE**

The study was directed at the population of senior secondary school students in Lagos state. Sample selection was limited to the senior secondary (i.e. SS11) physics students in Lagos state. Using random sampling technique, 300, students formed the study sample. Level of attainment in the chosen topics was the main consideration for samples.

## **INSTRUMENTS.**

The major instrument used in this study is practical skill test (PST). It is a test of skills and aptitudes, with dynamic characteristics. It focuses on specific skills (i.e. labeled A to J) measured and relates them as they cluster in specific aptitude in any work situation. The skills were grouped into three main sections namely:

- (1.) Identification of all forms of relevant knowledge, tools and equipment as pre-requisites for preparation, planning and design needed for carrying out the work. It is called identification test(X) consists of battery of skills.
- (2.) Undertakes of all the relevant processes of operation including steps taken to use organization management to optimize results. This called Test(Y) consists of battery of skills.
- (3.) Evaluation of all steps taken in (1) and (2) above in operating the completed work as a final product. This is known as product Test (Z) consists of battery of skills.

The students were asked to perform this task on B refraction of light. The test lasted for two hours. The outline for carrying out the test was given to ensure uniformly in assessment, prior to the administration, physics teachers were taught & trained for eight weeks on how to assess students during the work sessions. The frequency constant is undertaken to measure successful demonstration of skills, a SCORE OF ONE (1) is credited for skills success and a SCORE OF ZERO (0) for skill failure. Simple summation of occasions of successes was undertaken after each step of skill performance.

The reliability of PST was estimated using Kuder-Richardson formula 20(KR-20) and this yielded an estimate of  $R_h = 0.84$ . This is quite high considering the sample used in this study. The concurrent validity of PST was checked using a parallel but well established test, known as the physics potential test developed by Bayelo in 2000. The Pearson product moment correlation coefficient of  $r_p = 0.90$  was obtained attesting to its validity. Also, the test was presented to experts on the field of testing and science education who face validated it.

### **Skills Assessment Scale**

All assessment scales for practical work can be described as practical work: skill dimension vs. work sequence as laid out in table 1

Table 1: Standard profile on verification of hook's law.

	Dimension	X Identification	Y Process	Z Product
Preparation	A	6	3	-
	B	6	3	-
	C	4	4	2
Optimizing of process	D	2	4	-
	E	-	4	-
Process Operation	F	-	6	-
	G	2	10	1
Valuing of process	H	3	8	2
	I	-	2	6
	J	-	-	2
Total		23 (28.75%)	(55%) 44	13 (16.25%)

The frequency counts of identification (X), process (Y) and product (Z) work sequences were 23,44, and 13 accounting for 28.75%,55%, and 16.25% of total work sequence respectively (as specified in PST scoring techniques). Pre-requisites knowledge skills is made up of skill dimensions, A,B &C and performance evaluation skills consists of H,I,and J.( Details of operation of scoring procedures are fully documented in Adeyemo,2003).

Let  $X + Y + Z = Q$  (Practical work Sequence)

$$\text{Identification: } \frac{X}{Q} \quad 100\% = \frac{23}{80} \times 100\% = 28.75\%$$

$$\text{Process: } \frac{Y}{Q} \quad 100\% = \frac{44}{80} \times 100\% = 55\%$$

$$\text{Production } \frac{Z}{Q} \quad 100\% = \frac{13}{80} \times 100\% = 16.25\%$$

The absolute score obtainable on the marking scheme constitutes the standard against which the profile of student's personal skill performance may be judged towards a proper classification. To be a skilled worker one must be in possession of all relevant scientific facts, be able to read technical drawing and make relevant calculations encountered in the course of problem solving which the work involves, apart from all the process skills required for carrying out the work.

Generally, the ranges for the various work sequence for problem-solving are as follows:

$$\begin{array}{ll} Z \square X \square Y: & \text{product} \quad 13 \square Z \square 17 \\ & \text{Identification} \quad 28 \square x \square 32 \\ & \text{Process} \quad 53 \square Y \square 57 \end{array}$$

Any measures outside the ranges are abnormal.

All assessment scale for problem-solving can be described as problem-solving: skill dimension vs. work sequence as laid out in table 2.

Table 2: Standard profile on verification of Hooke's law in physics.

	Dimension	X Identification	Y Process	Z Product
Preparation	A	12	12	15
	B	-	6	10
	C	-	6	10
Optimizing of process	D	-	-	-
	E	-	-	-
Process Operation	F	-	3	5
	G	-	3	25
Valuing of process	H	-	7	12
	I	-	-	2
	J	-	-	-
Total		12 (9.38%)	37 (28.9 %)	79 (61.72%)

The frequency counts of identification, process and product work sequences are 12, 37 and 79 accounting for 9.38%, 28.9% and 61.72% of the total work sequence respectively. Details of null auditing system is fully presented in Adeyemo, (2003)

$$\text{Practical: } \frac{K}{N} \quad 100\% = \frac{12 \times 100\%}{128} = 9.38\%$$

$$\text{Strategic: } \frac{L}{N} \quad 100\% = \frac{37 \times 100\%}{128} = 28.91\%$$

$$\text{Empowering: } \frac{M}{N} \quad 100\% = \frac{79 \times 100\%}{128} = 61.72\%$$

The class average of data collected based on the above chart is bound to show the same trend with data obtained from specialist marking scheme. The absolute score obtainable from the marking scheme constitutes the standard against which the profile of students' personal skill performance may be judged towards a proper classification.

Generally, the ranges for the various work sequence are as follows:

K + 2; L + 2; M + 2; K < L <

$$\begin{aligned} \text{Practical} &= 8 < K < 2\% \\ \text{Strategic} &= 28\% < L < 32\% \\ \text{Empowering} &= 58\% < M < 62\% \end{aligned}$$

Any measures outside the ranges are abnormal.

### Aptitude Assessment Scale

An assessment scale for aptitudes can be conceived as one in which, as defined earlier, a cluster of skills (the aptitude) is being assessed. In this case, several skills in the cluster are assessed simultaneously in six distinctive. This means that the task involved in the work are separated into individual skills types and sorted into the various components of a basic aptitude suggested by McCarthy (1972). These are verbal perceptual, quantitative, general cognitive, memory and motor.

To aid the process of sorting the skills, A – J skill dimensions are held against McCarthy's six aptitude scales as exemplified on tables. Each of the letters A – J represents as set of qualities ranging from 7 – 10 which describes and the characteristics of the skill dimension under focus.

Note: Any measures outside the ranges are abnormal.

Skill and Aptitude in a task (e.g. germination of seeds) can be analysed using the table 3.

Table 3: Standard profile on biology practical work: germination of seeds.

	Skill dimensions	Aptitudes						Total
		V	P	Q	GC	Me	Motor	



Identification Tasks	A	6	9	3	13	6	7	44
	B	6	9	2	13	6	7	43
	C	6	4	2	8	6	2	28
Process (doing) task	D	1	7	2	7	1	6	24
	E	1	5	2	5	1	4	18
	F	-	7	2	7	-	7	23
	G	-	5	2	5	-	5	17
Product/valuing tasks	H	-	2	-	3	-	2	7
	I	1	4	-	4	-	-	9
	J	1	3	-	3	-	1	8
	Total	22	55	15	68	20	41	221
	%							

Table 3 clearly links skill dimensions to aptitudes using a science task. It shows that V, P, Q, GC, Me and Mot are related to skills dimensions A to J in their respective proportions.

\*Aptitude scales

- P = perpetual performance
- Q = quantitative
- GC = general cognitive
- Me = memory
- Mot = motor
- V = verbal

Where  $V + P + Q = GC$ . In essence, a basic aptitude is made of at least one each of V, P and Q with memory and / or motor being pre-requisites in some cases.

In order to analyse the components of aptitude present in a task, reference should be made to eighteen standard abilities, broken into their components among McCarthy's six (6) aptitude scales.

Note: Any measures outside ranges specified are abnormal and should be verified and a programme of restoration and rehabilitation should be used for adjustment.

### Reporting on Student's Skill Performance

So far, measurement in skill performance itself is in its cradle. Assessment in skill performance is in the experimental stage. Hence, reporting on students' skills performance is still rather speculative. It is a new field that will develop with time. The identification of A – J skill dimensions has facilitated the skills into four categories of:

- (i) preparations (to undertake work processes)
- (ii) operations (of work processes)
- (iii) optimization (of work processes)
- (iv) valuing (of work processes and product)

This can be seen in tables 1 and 2 set against the A – J skills. Once the frequencies of the A – J skills are summed by simple tally through all the stages of the work sequences, simple percentage is used to estimate the proportions constituted by various skills at every stage of the work sequence.

From comparison of the personal profile version of the SAT with the standard profile, strengths and weaknesses of students can be highlighted and reported upon along the four categories listed above. The implications of this for diagnosis, prognosis, remediation, selection, placement, admission to further training are obvious. Comments are not always needed except for the extreme cases of excellent or poor performance as they serve as models to be encouraged or discouraged.

An example is:

“A student is excellent in process operations, but some improvement in preparations and optimization skills could make for higher performance.

### **Discussion**

The realization that modes of assessment were ill-matched to modes of instruction in the pursuit of mastery learning from goal-based instruction (Bloom, 1956) to “Constructivism” in STM, (Yager 1990) triggered off skill-focused instruction. It became clear that our current perception of instructional leadership and associated cognitively-biased assessment procedures had to be changed (Baiyelo 2000). This led to the evolution of a simple assessment procedure involving the analysis of skills in any piece of work which was subjected to reasoning and skills analysis (Baiyelo 2000) and it became clear that

- (i) Students need to attain requisite level of reasoning and acquire relevant skills and positive attitude to succeed in undertaking productive work.
- (ii) Work in science, technology and mathematics demands both mental and manual skills for a good performance in practical work and problem-solving.

From the foregoing the need has risen to correct the age long assumption that science students need only good performance in process skills to achieve well in science. We are now aware that quite apart from reasoning skills and process skills; science students need organization and management skills, to optimize their sciencing affairs. Besides, they also need extra skills in identification of their tools, devices and laboratory resources, equipment and apparatus.

A major omission of the cognitively biased current assessment system is the absence of any reference to students’ progress in the acquisition of skills related to preparations, operations, optimization and valuing of work done in their report card. This is totally unfair as the listed skill areas have direct bearing to the same activities to which cognitive assessment gives due credit for reasoning skills alone (Baiyelo, 2000e)

The current attempt to focus on skill assessment seems a relief from the omissions to the past. Students’ report cards can now carry teacher’s comment on aspects of skills in which students are strong or weak. This opens the way to improved career guidance at school and preparations for the world of work. Such comments should be helpful for diagnosis and

prognosis remedial instruction and general research towards students' overall improvement as well as for selection and placement into jobs positions, admission into training programs and generally for further education.

### **Conclusion**

In observing an individual's behaviour, one can identify recurring response sequences. These recurring response sequences tend to become modified and more refined with repetition. They are better referred to as skills. The identification of a common skill for several individuals permits the definition of skill categories. The number of skill categories/dimensions required for a given work/task is, however, extremely large. It is cumbersome to describe an individual's response in terms of many skill dimensions. A more succinct system of description is feasible through the application of modern mathematical methods such as factors analysis (Harman, 1960); it is possible to identify a small number of more basic dimensions that underline the several skill dimensions. These more, basic dimensions represent common elements in skill dimensions and are called ability-dimensions. Obviously, there are fewer ability dimensions than skill dimensions. It is more feasible, therefore, in terms of both economy of time and comprehensiveness of scope, to describe individual in terms of skill dimensions. Little wonder, if skill performance statements are stated in terms of ability. Hence one can say that aptitude begets skilled performance and skilled performance begets success in productive work. In effect, these concepts are interdisciplinary and hierarchically related, besides they are all encapsulated in productive work.

Consequently, every teacher needs to understand the concepts of skill measurement assessment and evaluation. An understanding of how these concepts inter-relate and interoperate is imperative for a proper conceptualization of the value of work which draws its meaning from a total commitment to the values of these relationships.

What is required to close the gap between school and work is the cultivation and reinforcement of relevant skills and aptitudes. The extent to which skills most neglected will be identified, their acquisition and reinforcement mastered and their measurement, assessment explored and scaled and the precision with which their impact on student's achievement could be evaluated should become the focus of instructional leadership in the new millennium. The skills of economy and parsimony as well as those of organization and management presently neglected in science, must, with time, gain the focus of instructional leadership if we must attain mastery in simulating education and productive work and make school science become of greater service to technology in the next decade.

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