Breaking Barriers to Meaningful Learning of Science

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Introduction

The twin goals of this paper are to identify major barriers to meaningful learning of science and undertake an examination of strategies that have proved potent in breaking down such barriers. The underlying intent is to seek pathways for winning more youth in Africa for science and assure improved performance especially through learning at the deep rather than rote level. For the purpose of the paper, science is applied to cover science, technology and mathematics (STM) and the more recent conglomerate- science, technology, engineering and mathematics (STEM). The assumption undergirding the paper is that if the conditions are right, and African youth learn science meaningfully, Africa's early lead in science, technology and innovation lost in the 16th century can be reclaimed in the 21st. What are the highlights of this early lead?

Down through the ages and up to about the middle of the 16th century, Africa played avant-garde role in science (Okebukola, 1997; Shillington, 2005). One of the first intensive agricultural schemes, and metallurgy (including the mining and smelting of copper) were practised in Africa as far back as 4000 B.C. The system of hieroglyphic writing and the use of papyrus, the science of architecture also reached new heights with the pyramids. They were amazing accomplishments both in terms of construction and the mathematical and astronomical knowledge necessary to build and situate them. Between 3000 and 2500 B.C., calendar and numeration systems were developed and a carefully-defined medical system was established under the guidance of Imhotep, an African physician and architect. The Egyptians were responsible for many medical innovations. In addition to developing an elaborate herbal tradition and many methods of clinical therapy, they also devised a code of medical ethics. However, in spite of this apparent early lead, Africa remains, today, in the back seat in science and technology development (UNESCO UIS, 2011).

One of the catalysts for Africa's slip from the "tower of science" (Shillington, 2005) is the decline in participation and achievement of students in science. Recent literature is replete with evidence that students' performance in secondary science is falling short of expectation in most, if not all countries in Africa. Data on underachievement have, for example, been reported for Kenya (KNEC, 2009; Muraya & Kimamo, 2011) Ghana, Nigeria and Sierra Leone (STAN, 2010; WAEC, 2009, 2010) and South Africa (Reddy, 2006; Republic of South Africa Department of Education, 2009). The 2009 report on the state of education in South Africa concludes that "children are not learning nearly as much as they should be learning, or could be learning, is inescapable… and much more needs to be done to boost measurable cognitive achievement".

Probes into the aetiology of the problem consistently reveal that many students attain the shallow and superficial level of concepts (Dzama & Osborne, 1999; Taylor, 2008; Asikhia, 2010; Okebukola, 2011; Mbugua, Kibert, Muthea, & Nkonke, 2012) in contrast with the desired goal of deep or meaningful learning (Novak, 2002; Hamilton, Mahera, Mateng'e, & Machumu, 2010;; Okebukola, 2010). This development is stimulating nervousness in many African countries since national development is inextricably linked with prowess in science and technology (UNESCO UIS, 2011), hence inability to win the youth for science and ensure their success will deplete the ranks of future scientists needed for research, innovation and development and for fostering socio-economic growth.. African countries are under-served with scientists relative to the other regions of the world (UNESCO UIS, 2011). In spite of the 2010-2012 impressive 6-8% GDP growth of many African countries, the outlook for the coming decades may be dim (noting the forecast for China's retardation in economic growth), if sufficient attention is not turned to catching African youth young for science and ensuring that they learn science meaningfully.

The call to improve the delivery of science and technology curriculum in Africa has been more strident in recent times, especially through three channels. In January 2007, the African Union declared 2007 as the year of launching and building constituencies and champions of science, technology and innovation in Africa. It agreed on Africa's Science and Technology Consolidated Plan of Action (CPA) as a common platform for policy, research and development programmes that contribute towards achieving the vision of the AU of integration, socio-economic development and positioning of Africa in the global economy, through the development and use of science and technology. The CPA has three interrelated conceptual pillars- capacity building, knowledge production and technological innovation. The capacity-building thrust has a segment focusing on delivery of quality science education at the basic and higher education levels. Since 2007, AU has been taking steps to achieve its CPA goals. Indeed, the African Union Second Decade on Education (2006-2015) also recognises the importance of technical and vocational education and training in Africa's development especially in the quest towards poverty alleviation and eradication. The objective of the training is to "re-align education systems in Member States so that young people are provided with compulsory basic education which imparts key generic competencies, skills and attitudes that lead to a culture of lifelong learning and entrepreneurship in order to empower individuals to live in peace and harmony, engage in the world of work, alleviate poverty and pursue further learning".

Secondly, African Ministers of Science have stressed the need to promote science, technology and mathematics at the basic education level in order to guarantee good foundation for tertiary-level science. The African Ministerial Conference on Science and Technology (AMCOST) of May 2012 agreed on strengthening science, technology and innovation (STI) by improving science, technology and mathematics education, enhancing scientific research and ensuring that higher education systems are equipped to meet the demand for jobs, especially among the youth. Participants also reflected and agreed upon initiatives for harnessing global innovative solutions to address development challenges in agriculture, health, water and energy, and ICT sectors through quality delivery of secondary science. At a preceding one-day AMCOST held on April 4, 2012 in Kenya, the Director-General of UNESCO, Irina Bokova, underscored the vital role of quality basic science education and observed that "Africa is on the move today. Science, technology and innovation is vital in maintaining this momentum. Our vision is clear, but we must do more to defend it -- social equity, environmental protection and sustainable, green economic development are part of a single agenda. We need an integrated scientific research agenda to better understand the world, to identify boundaries and tipping points".

The third is the African Academy of Sciences with one of its mission statements as "convening and coordinating science education programmes of crucial importance to Africa as a whole". The Academy has consistently underscored the need for African countries to take urgent steps to address causes of students' underachievement in science. Taken together, these concerns accentuate the need to steer our gaze, sharper than before, at the issue of improving quality in the delivery of science education especially to promote meaningful learning.

Meaningful learning in science

It is not the intention of this paper to be expressive on the psychological roots and ramifications of the concept of learning and within this literature, undertake an extensive discussion on meaningful learning. In focus will be the extraction of key issues and debates which are considered directly relevant to the goals of the paper.

Students learn when they acquire new knowledge or adjust existing knowledge to accommodate incoming information (Novak, 2002; McNeill, Lizotte, Krajcik, & Marx (2006). The growing literature on how students learn especially within the schema tradition (Novak & Gowin 1984; Novak &Wandersee, 1990; Novak, & Musonda, 1991; Novak, & Iuli. 1995) converge to indicate that when new information is received as sensory data, the learner assigns it to a new organising framework known as schema (Novak, 2002; Ausubel, 2000). For instance, a secondary school student being taught cellular energetics for the first time, creates a schema or schemata (plural) on energy transformation from the breakdown of a complex carbohydrate through a monosaccharide to CO_2 and H_2O with the release of energy used by the cell for its several functions. With practice, rehearsal and use of the new knowledge by the student, the information moves from the short-term memory through medium-term to the long-term memory store. Here, it is retained for a long time, almost indefinitely (Novak, 2002)

In another class, this time chemistry, on the topic of oxidation, the same student encounters information that supplements or adds to what was learned in the biology cellular energetics class. The earlier schema formed by the student, accommodates the new information from the chemistry class through a process of assimilation. Over series of science lessons, the student builds new schemata and readjusts existing ones, a process which leads to meaningful learning.

There are several theories and models which describe meaningful learning (Ausubel, 2000). For the purpose of this paper, we shall pitch on the side of the Ausubelian model for the reason of its being the most cited and one which our research in Nigeria and Australia had been built over the last 30 years. In *The Psychology of Meaningful Verbal Learning* (1963) and later *The Acquisition and Retention of Knowledge* (2000), Ausubel made the distinction between *rote* learning where new knowledge is arbitrarily and nonsubstantively incorporated into the cognitive structure, that is, into long term memory, LTM, and *meaningful* learning where the learner chooses conscientiously to *integrate* new knowledge to knowledge that the learner already possesses. As Novak (2002) notes, young (preschool) children are adept at meaningful learning, but upon entering formal schooling, too often with overwhelming emphasis on rote memorisation and verbatim recall of answers for tests, most learners move to rote learning.

In the process of learning, concepts are combined to form statements or *propositions*. Knowledge stored in our brain consists of networks of concepts and propositions. As meaningful learning proceeds, new concept meanings are integrated into our cognitive structure to a greater or lesser extent, depending on how much effort we make to seek this integration, and on the quantity and quality of our existing, relevant cognitive structure (Novak, 2002). Novak (2002) observes that if we learn strictly by rote, essentially no integration of new concept meanings occurs, and existing cognitive structure is not elaborated or reconstructed. Because individuals vary in the extent of their existing relevant cognitive structure, and also the effort they make to incorporate new concept meanings, there is a continuum in learning from extreme rote learning to highly meaningful learning. In a learning setting, our intention as teachers is to move students from their entry point A to a higher point B where we expect the learning of the concept to have taken place. Between these two points of input and output is the process of instruction which we expect, should lead to learning.

Meaningful learning can best be described by contrasting it with its obverse - rote learning. To bring this contrast to sharp focus, let us work through by way of an example. Take a Basic 3 pupil (about 9 years of age) who is able to flawlessly recite the multiplication table from 2 to 5.

> ***Teacher:*** Tunde, what is 3 times 2?
> ***Tunde:*** (a pause) Six.
> ***Teacher:*** What about 3 times 9?
> ***Tunde:*** (a long pause during which Tunde is muttering: 3 X1 =3; 3X2=6; 3X3=9... 3X8=24; 3X9=). The answer is 27.
> ***Teacher:*** Good. Now Tunde, if a bus can carry nine people, how many of such buses will be required to carry 27 people?
> ***Tunde:*** I am sorry Sir; I don't know. We have not done division in our class.

Tunde obviously learned by rote and unable to transfer the knowledge to a novel setting.

Rotely and meaningfully-learned materials are organised quite differently in the cognitive structure. Meaningfully-learned materials have been related to existing concepts in the cognitive structure in ways making it possible for the understanding of various kinds of significant (e.g. derivative, correlative, qualifying) relationships. Most new ideational materials that students encounter in a school setting are relatable to a previously learned background of meaningful ideas and information. Rotely-learned materials, on the other hand, are discrete and relatively isolated entities which are only relatable to the cognitive structure in an arbitrary, verbatim fashion. Secondly, because they are not anchored to existing ideational systems, rotely-learned materials (unless greatly overlearned or endowed with unusual vividness) are much more vulnerable to forgetting, that is, have a much shorter retention span. These differences imply that rotely-learned materials are essentially isolated from cognitive structure and hence are prone to interferences of various kinds (e.g. the interfering effects of similar learning materials learned immediately before or after the learning task.

Meaningful learning on the other hand, occurs when the student has been able to internalise information in the long-term memory store. The student who has meaningfully learned a concept is able to easily recall the information and apply the knowledge of the concept in solving novel problems. Take two students who have been taught electric circuits in the physics class. One of the students is able to redraw the electric circuit but not able to fix an electrical problem arising from a break in an electric circuit e.g. a non-functioning pressing iron. The other is able to identify the problem of the faulty iron as a break in circuit and correct the problem. Student B could be said to have meaningfully learned the concept of electrical circuits. Let us now identify key barriers to meaningful learning of science.

Barriers to meaningful learning of science

The science education literature is rich with reports on factors which hinder meaningful learning of science. Input and process factors have been documented. The organising scheme in this paper is a clustering around findings from our research group. We shall present the barriers relating to the subject, learner, teacher, teaching environment and culture.

The Subject as a Barrier

It is a commonly held view among students that science is difficult to learn (see review by Okebukola, 2011). This point of view is reflected when students are to make choices. Fewer students elect to study science subjects when compared with the arts. This phobia of the subject inhibits motivation and interest which in turn stifles learning. In 2008, 82% of the 3,803 secondary school students in a national survey in Nigeria claimed they dislike science because it is difficult to learn. Excerpts from interview data are:

Bayo: I am always very scared of science especially chemistry and physics. Physics has too many calculations. Chemistry has too many formulae and equations. I forgot biology. I do not like drawing.

Xty: For me, science is too difficult. I spend too much time reading it and I learn nothing. I spend less time reading my arts subjects and I learn a lot.

Audu: Only gifted people can do science. The subject itself is too difficult. I am not gifted and will not deceive myself studying science beyond SS1.

Several studies have reported similar findings in Australia (Fraser, Aldridge, & Adolphe (2010) UK (Jenkins, 2006) and Kenya (Muraya & Kimamo, 2011). It is unclear whether these findings are uncovering difficulties relating to science as a subject or to the resultant of science when not properly taught. What is however clear is that science as a subject has certain inherent attributes that predispose it to being difficult to learn. So, what are the attributes? Two attributes of science have been documented by the impressive corpus of research on the nature of science to be language and epistemology. Science has its special language of concepts, propositions, formulae/equations and diagrams- which is not the language of non-science subjects. Consider a chemistry lesson on types of reactions for senior secondary 1 students. At the end of the lesson the board had the following entries:

- The decomposition reaction is depicted as
  $C_{12}H_{22}O_{11}$ (s) $\rightarrow$ 12C (s) + $11H_2O$ (l)
- An example of a synthesis reaction is:
  2Mg (s) + O_2 (g) $\rightarrow$ 2MgO (s)
- An example of a single replacement reaction is:
  Zn (s) + 2HCl (aq) $\rightarrow$ $ZnCl_2$ (aq) + H_2 (g)
- An example of a double replacement reaction is:
  $Pb(NO_3)_2$ (aq)+ 2NaI (aq) $\rightarrow$ $2NaNO_3$ (aq) + PbI_2 (s)

The economics lesson for the same class has the following end-of-class entry on the board.

- We have already decided that economics is a study of <u>choices</u>.
- We must make choices because we have limited resources.
- Scarcity is simply the concept that human wants (<u>not</u> human needs) exceed the resources available.
- Thus, scarcity is fundamentally the most important concept in economics, upon which all of the rest of the discipline rests.
- Without scarcity, there is hardly any need for choice.

It is obvious that the ‘typical’ student will feel less intimidated by the content of the lesson in economics than the chemistry lesson. This leads us to the tentative conclusion that science by the nature of its language, is a difficult subject for students (Novak, 2002). It is also a widely received view that it is easier for a science graduate later to pick up expertise in a non-science subject than vice versa. A humanities undergraduate straying into a final-year physics or chemistry lecture would be very unlikely to understand much of what is going on, yet many science undergraduates could wander into a corresponding lecture in the humanities e.g. history and would at least be able to follow some of the message of what was being said. Both the sciences and the arts may be equally 'hard' to do well, but science is found by students to be typically harder.

The difficulty according to Millar and Osborne (1998) lies in the 'distance' between the language of science and the local language of the learner. Compared to disciplines like history and literature, the language of science is distanced from vernacular language. Science involves logical chains of argument, couched in abstract language. In other subjects, where language and ideas remain closer to the vernacular, learners can draw on lay understanding to make sense of the discourse of the subject. The greater 'distance' of science discourse from everyday discourse makes this much more difficult. If, in addition, this abstract language is written in a symbolic form - mathematics - the difficulty becomes greater still. Millar and Osborne (1998) give more insight by describing intrinsic and extrinsic reasons. Intrinsic reasons are the consequence of certain unavoidable characteristics of science and/or of learners; while extrinsic reasons are the consequence of decisions by science teachers and educators, which have the result of making science harder to learn than it actually needs to be.

There is, for instance, a marked reluctance on the part of many science educators to acknowledge that science is a consensually accepted body of knowledge, and a tendency instead to portray science primarily as an algorithm for obtaining knowledge of the natural world. Again contemporary philosophy of science has drawn attention forcefully to this deep tension within science between openness and scepticism on the one hand, and dogmatism on the other. This too is most commonly associated with the work of Kuhn but is also implicit in the writings of Popper. Science has an ethos and an associated rhetoric of openness to empirical findings and ultimate scepticism about current theoretical positions; all claims are open to testing by anyone who wishes, and no theory is claimed to be the final say on the matter. On the other hand, science has the most consensually agreed body of contents and practices of any developed discipline.

Because much of science is well established and consensually agreed, it is natural that the teacher will want to lead his or her class efficiently to the accepted understanding of the area they are working on. A consequence is that science can come to look like a simple description of the world - a reading of the book of nature - rather than the creative business of 'making sense' (Millar and Osborne, 1998). In part this arises because the time and facilities to explore fully the evidence for most important scientific ideas are simply not available. As a result, classroom treatments often distort the nature of scientific evidence, by requiring that the learner accepts the conclusion without access to adequate evidence for it. This makes science appear as a large collection of relatively 'useless' facts to be learnt. It also obscures from learners the overall purpose of science - a search for persuasive explanations about the nature and behaviour of the natural world.

The Learner as a Barrier

Readiness, motivation, cognitive preference orientation and general attitude to work are some attributes of the learner that pose barriers to meaningful learning of science. Several studies (see reviews by Okebukola & Jegede, 1988; Okebukola, 2011) have provided evidence that many Nigerian children at the primary and secondary levels are not cognitively ready for the type of science that teachers present. It has been established by these researchers and others, that teachers are presenting formal-operational concepts in science to students who are predominantly concrete operators. This is what has been described as cognitive mismatch rather than capacity deficit in explaining students' underachievement in science. This Piagetian position, is taken to contrasts with the Ausubelian position that any subject matter can be taught to any child in an intellectually honest way if given enough time and within a conducive learning environment. Without engaging in the discourse conflict between Ausubel and Piagetian on this issue, studies conducted in Nigeria point to the position that many students are not mature in their cognitive processing abilities to be able to effectively learn some science concepts (Okebukola & Agholor, 1991).

On the issue of motivation, data have been provided e.g. by Alaiyemola, Jegede & Okebukola (1990) that the motivation level of many Nigerian students is low. With motivation level clearly a factor in meaningful learning, this low level of motivation could be seen as a barrier to meaningful learning of science. Closely tied with this is the widely reported poor attitude of students to work (Okebukola, 2011). Ask many science teachers and they will tell you how lazy their students are. Cases of refusal to do assignments and cutting classes are widely reported especially in public schools.

The Learning Environment as a Barrier

In a study conducted in 1989, we compared the preferred and actual science laboratory environments in Australia, USA, Israel and Nigeria. The preferred environment is a description of how students want their laboratories to be. The actual environment is the description of how the science laboratory is (at the time of the study). On all our measures, the Nigerian sample showed the greatest gap between the preferred and actual (Fraser, Okebukola & Jegede).

The actual science laboratories are far from equipped for meaningful science teaching and learning. Even the classrooms are poorly equipped. Over-populated classrooms are common place. Classroom settings with no roof and scanty furniture in many cases, are far from enabling in promoting meaningful learning.

Culture as a Barrier

Our studies have shown a number of factors that enhance science learning and some that are hindrances from the perspectives of African culture. Cultural barriers which we identified in our studies (e.g. Okebukola & Jegede, 1990; Jegede and Okebukola, 1991a; 1991b; 1992; 1993) are superstitious and taboos and language. These factors have emerged over the years to impede the access, participation and performance of students, especially girls in science. Onwu (2011) argues that natural and social worlds have co-evolved in cultures, and that focusing on cultural issues on how we teach science is one way of ultimately seeking to increase the socio-cultural relevance of science and science education for improved access and motivation. Onwu (2012) underlines the value of indigenous knowledge (IK) and the recommendation of its integration into the national curriculum statements. He posed the following questions: Is IK in synch or congruent with science especially when it is more nuanced and more specific to a given locality-its localness? Is it meaningful and relevant to learners' life experiences? Does it serve as a useful link between home/community and school based experiences? Will it boost the morale and enhance the sense of self worth of the local indigenous community? Can it be extrapolated or applied to other contexts or similar situations?

In our recent study (2011-2012) entitled "Some Socio-Cultural Factors Impacting Scientific Explanations by Biology Students: A Nigerian Case Study", we noted an emerging and worrying trend in the declining performance of students in tasks demanding scientific explanations. Whereas scores on test items on recall of facts and definitions in the Nigerian senior school certificate examination have been found to increase slightly over the years, performance on test items demanding explanation has continued to take a dip. The design was a case study involving qualitative and quantitative data-gathering techniques implemented over a 9-month period. There were two participating secondary schools located in Lagos in the south-western part of Nigeria. Students enrolled in the school are from a broad spectrum of cultural backgrounds in Nigeria in terms of language, religious affiliation, socio-economic status and habitat (rural/urban location of residence). The 218 students (96 girls, 122 boys) with mean age of 15.4 years were enrolled in senior secondary biology. About 18% of the students live predominantly in rural areas. Within this group, 52% are from fishing communities in coastal areas, 41% from peasant farming communities in the hinterland while others are from villages where petty trading predominates. The bulk of the students, that is 72% grew up and live in urban centres. The socio-economic status of the families of most of the students was classified largely as middle-level. A small fraction (5%) especially those from rural communities belongs to the low socio-economic group.

Five regular biology teachers in the selected schools and the lead researcher taught the biology lessons during the course of the study. Over a 9-month period of being participants in biology classroom transactions, the students were sufficiently relaxed to freely express themselves during the interview phase of the study. During the course of the study and via the medium of fortnightly tests, students were asked to provide explanations relating to biological concepts learned during every two weeks of class instruction and laboratory work. The typical class during the period consisted of whole-class lectures and small-group discussions. The laboratory sessions were mainly teacher demonstration with occasional small-group or individual hands-on exercises when biological specimens were ample.

Every week, students had 90 minutes of biology class time. This featured one week of classroom instruction alternating with laboratory work the other week. Class session typically begins with teacher reviewing previous lesson. This is followed by presentation of content for current lesson during which ample room is given for student participation through questions and answers. Class concludes with teacher summarising the lesson and giving out assignments. The laboratory work normally begins with teacher demonstration. This is followed by student individual or group work. The topics covered during the course of the study were cells and molecules of life, diversity of organisms, Mendelian genetics, ecology- organisms and environment, plant and animal physiology, applied ecology, and biotechnology.

Each fortnightly test had a component which required students to explain a biological phenomenon or process. Answer scripts were graded using a scoring scheme with six criteria- (1) articulation of causal claims; (2) use of appropriate and sufficient evidence to support these claims; (3) use of reasoning that draws on scientific principles to explicitly link the evidence to the claim; (4) accuracy of reasoning; (5) application of appropriate scientific principles; and (6) correct sequence of events. This scheme is a blend of the marking scheme of the West African Examinations Council for Biology and the rubric proposed by McNeill, Lizotte, Krajcik, & Marx, (2006). The five biology teachers who were trained using the scoring scheme (inter-rater reliability of 0.89), graded the scripts under the supervision of the lead author. During the 9-month duration of the study, a total of 3,924 scripts containing answers to questions demanding explanation of biological phenomena were graded. The scores of the 218 students were grouped into high (upper 25%), average (middle 50%) and low (lower 25%). Every two months, a random sample of five students from each group was interviewed to seek in-depth information on why they offered the explanation to the biological phenomenon in their answers. Interview sessions took place during class free periods and lasted about 20 minutes on the average for each session. Interview data were audio recorded, transcribed and coded. The teachers noted the socio-cultural attributes colouring each explanation. Follow-up reviews by the research team aggregated five socio-cultural attributes of the explanations namely language, habitat, religious orientation, socio-economic status, gender.

Language: About 43% of the explanations were influenced by the degree of fluency in the language of writing the explanation. This supports findings of previous research (Thomas and Collier, 2002) that language is a key factor in teaching and learning. Chukwu, one of the target students presented a rich and detailed explanation of the question: Explain how energy flows from one trophic level to the next in an ecosystem”. Chukwu wrote:

> In an ecosystem, the energy from the sun is trapped by green plants that are primary producers at the bottom of the pyramid. When green plants are eaten e.g. by a goat (primary consumer), the energy is passed to the primary consumer. Part of this energy is converted to body heat. If the primary consumer is warm-blooded, it will eat more plants because of the energy loss, but if cold-blooded like a lizard, it will eat less. Energy flows to secondary consumers e.g. a hawk when they eat primary consumers. Tertiary consumers such as man finally get the energy by eating secondary consumers. At each level, energy is lost so man gets very little at the end of the day.

Interview data confirmed that Chukwu grew up in a home where English, the language of instruction in schools, is the primary language of conversation. He narrated: “at home, my parents give us support to read English books and newspapers”. Comparison of the explanations of Chukwu of energy changes in the ecosystem with about 82% of those students with rich explanation shows great similarity in their level of English language fluency. In contrast, students with greater fluency in the mother tongue than English were less explicit in their explanations. Over three quarters of these students were in the average and low score category. Risi, a 15-year old girl in this group gave the following written explanation to the question: “Explain the process of movement of mineral salts from the soil to the leaf of a flowering plant”.

> ***Risi***: Mineral salts are taken by the root hairs to the plant. They move through the xylem to the leaves”.

It was however a different story when Risi was asked to explain the movement of mineral salts during the interview session. Using a mixture of English and Yoruba (her mother tongue), Risi explained in detail with accompanying rough sketches, how mineral salts enter the epidermal cells of root hairs by diffusion and active transport. The minerals (often called “mineral” by Risi in line with local pronunciation) are further moved by diffusion to the xylem vessels and pulled “by a force from the top” to the leaves. Intrigued by the level of detail in Risi’s oral explanation in contrast with the rather weak and sketchy written explanation, we inquired if time was a constraint in the test. Risi: “No sir. We had enough time. I cannot explain myself well in English. I don’t want the teacher to punish me if I make English mistake”. When we explored this strand of evidence further, we found that 93.6% of those students in the upper 25% were in the high achieving group in the English language class.

Student habitat: Student habitat, that is where the student spends most of his or her time outside school was found to play a role in the biological explanations offered by the students. This reflected significantly in ecological concepts as students regardless of their group (high, average or low) copiously coloured their explanations in ecology with their rural/urban context. The question that exemplifies this trend is: "Using examples, explain the feeding relationships in a food web". Over 90% of students from the coastal area used aquatic environment examples. Their explanation had several common elements. A typical explanation given by Senapon in the average achievement group is:

> My example is an aquatic food web. Organisms in the water such as fish, water snails, water boatman require energy for daily life. The energy is derived by eating organism in the lower food chain such as planktons. The plankton get their energy from the sun. Several food chains in the aquatic environment are linked to form the food web. The energy used throughout the web comes from the sun.

Most of the students from the savannah geographic zone gave explanations on energy relationships within the savannah. Evidence from Sandoval and Millwood (2005) points in a similar direction.

Religious orientation, socio-economic status and gender: Explanations offered by students on sex-linked characters, albinism and human diseases were found to be largely coloured by religious orientation of the students. Socio-economic status and gender did not feature as discriminatory variables in the explanations throughout the course of the study. This is a refreshing finding since these two variables have been implicated in students' performance in science (Morrison, 2006).

The foregoing example while not generalisable across Africa, highlights the impact of socio-cultural variables on how students learn science. The study is contemplated for extension to other African countries to see if there are discernible continental trends.

Language of instruction as a Barrier

As we noted in our recent study (Okebukola, Owolabi and Okebukola, in press), the language in which instruction is delivered has long been established as a potent factor in student learning (see reviews by Benson, 2005; Dutcher, 1995; Kosonen, 2004). A rich corpus of literature has emerged for social studies teaching (Prah, 2003) and even for the teaching of language (Klaus, 2003). The extensive literature on cognition (Lycan, 1999; Stanley, Ward and Enns, 1999) converge to assert that language as an encoding medium provides the prop for meaning making and for activating mechanisms in the cerebral cortex to form neural connections which are basis for learning. Language of delivery of science through classroom discourse or presentation through textbooks is, therefore, a key determinant of concept formation and mastery. Since one of the core goals of science education is to facilitate student learning, language becomes an important issue to which attention of science educators should turn.

The exploration of the role of language in science learning has had a fairly long history. Towards the last quarter of the 20^{th} century, research efforts were invested at finding out how the nature and use of language benefitted or hindered science teaching and learning. Longitudinal studies by Fafunwa, Macaulay and Soyinka (1989) showed that the language of classroom discourse had positive attitudinal effect on how children learn science and their attainment of science concepts. Several other studies by Olarewaju (1991) and Blankson (2006) however found that the positive effect was mediated by student variables including need for achievement, home support and IQ. When taken together, the findings of research on language and science learning would appear to converge in suggesting an overall positive impact.

Emerging within the literature on language and science learning is a strand focusing on the use of the mother tongue. Mother tongue also known as L1, first language, language of one's ethnic group, dominant language, home language, native tongue, native language is the language learned from birth (from one's mother). It is the language of the home in which customs are transmitted and the child learns initial vocabulary. The key driver of this strand of studies is to inquire into the potency or otherwise of delivering the science curriculum in the mother tongue. A scan of the work in this area shows a quick rise in volume in the 1980s followed by a tapering off as the century closed. A resurgence is in the air in response to at least three forces. The first is to globalisation. Increased cross-border activities across nations is fostering inter-twining of world cultures. The European Union and the Economic Community of West African States (ECOWAS) present examples. In Europe, free movement of persons, goods and services across its 27 member states explains the variegated cultures including languages spoken that strike one in a public place such as a mall or school. Researchers are beginning to turn their gaze on how globalisation through this culture mixing especially the mother tongue of the immigrants is affecting science teaching and learning. In ECOWAS countries, there is trans-border movement of persons speaking English, French and a host of local languages which present a similar challenge.

Secondly and related to the first is multiculturalism. Multicultural classroom settings are growing in number worldwide, calling for a close study of the dynamics within such settings, especially the issue of the mother tongue for instruction. Thirdly, technology is advancing the cause of language with numerous translation apps. Translating from English to Swahili, a language that is widely spoken in southern Africa, French, Spanish or Portuguese is no longer arduous. This development has broken some of the barriers to translating scientific terminologies to the mother tongue and enhanced the delivery of instruction as well as the development of science textual materials in the local language. The stage would appear set for a heightened interest into how students learn science in such multicultural, multilingual settings especially in relation to the use of the mother tongue.

The decision to adopt the mother tongue for instruction at the lower levels of primary education in Nigeria, a multi-ethnic society, dates back to 1977 when the national policy on education was enacted. The Nigerian education system operates a 1-6-3-3-4 system. Five-year-old children are enrolled in one-year pre-primary, thereafter into a 6-year primary school system. Instruction in the first three years of primary education is expected to be delivered according to the policy which was revised in 2004 in the "mother tongue or language of the immediate environment" (FME, 2004).

In our recent study on the use of the mother tongue for teaching science and its effect on meaningful learning, we found the preponderant use of English as a medium of instruction in the primary science classes observed in the urban schools, less so for the rural. An interesting trend was the gradual increase in the intensity of use of English from primary 1 through to 3. Intensity in this case denotes the reduction in occurrence of the local language interspersing the use of English language. A science lesson with little or no injection of local language is taken to be more intense in the use of English compared with a lesson where the teacher explains some of the science concepts in the local language as the lesson progresses in English. On the average, science lessons delivered in primary 1 in rural settings, were found to be 93.6% in the mother tongue. In primary 2 this fell to 91.1% and in Primary 3 to 84.6%. In contrast, in the urban areas, mother tongue content was found to be 61.8% in primary 1, 49.2% in primary 2 and 26.6% in primary 3.

A lesson in the rural area on "Classification of Living Things" in primary 1 began with the teacher introducing the lesson in Yoruba (the language of the local environment and mother tongue of all the pupils), with specimens of insects, worms, plants, plastic bucket and stones. There is also a chart showing several plant and animal species as well as pictures of inanimate objects such as car, football and shoes. Teacher calling one of the pupils: "Tunde, fowo kan nkan elemi ninu awon aworan yi" (Tunde, point to a thing that has life in these pictures). Tunde points to a rat on the chart.

> ***Teacher to class:*** Se o gba (Is he correct?)
> ***Class:*** Ogba (He got it right).
> ***Teacher to class***: E pa 'tewo fun (Clap for him).

Class rewards Tunde with three short claps. The class progresses with many more pupils pointing to living and non-living things on the chart and the specimen table. After this, each pupil was asked to draw up a table of living and non-living things. The last ten minutes was spent on class discussion on the common elements among living and non-living things. The bell goes for change of lesson. The discussion on the attributes of living and non-living things was to continue in the next class. All teacher talk and student-student talk were in the local Yoruba language (see figures 1 to 3). The use of the language to which the pupils were most familiar, predisposed them to learning science (Jegede & Okebukola, 1989).

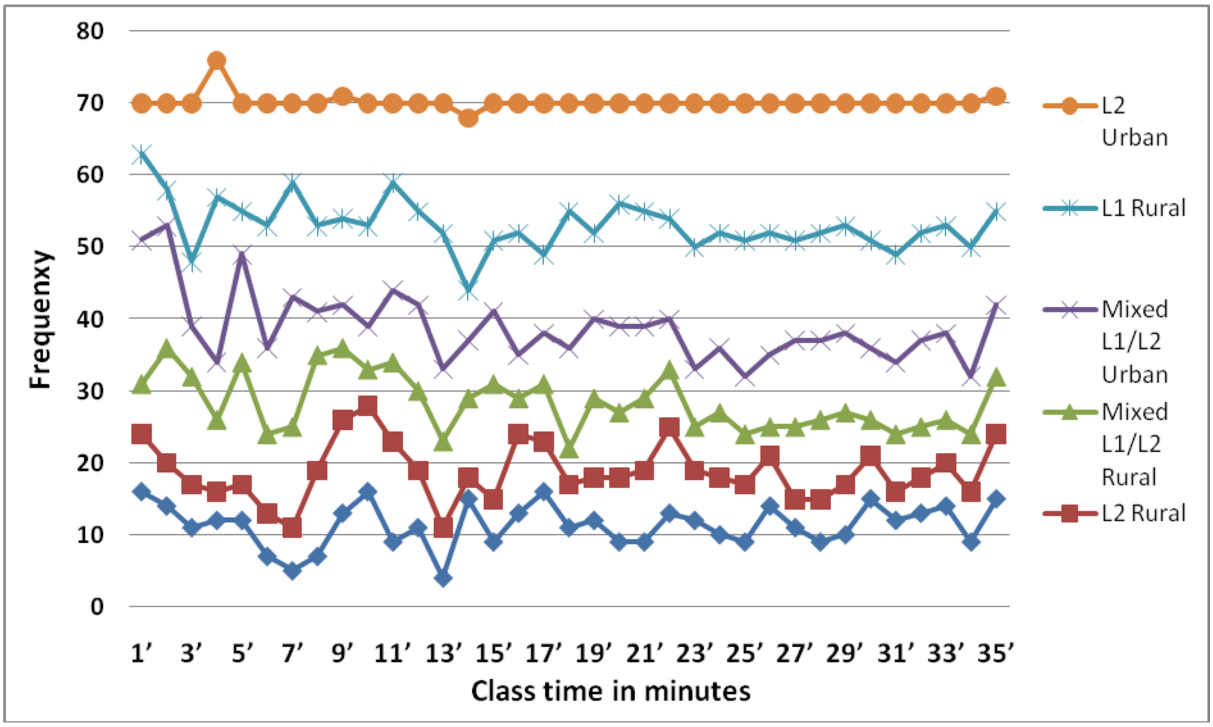

Figure 1: Primary 1: Language interaction profile across urban and rural schools

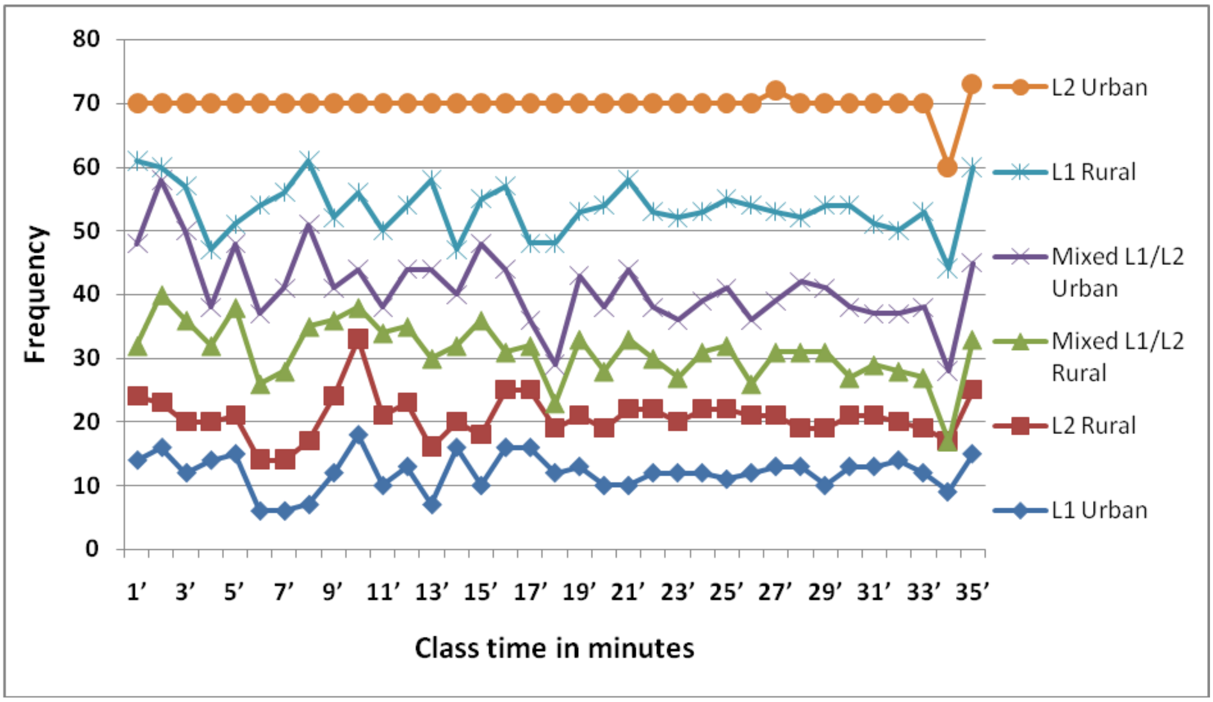

Figure 2: Primary 2: Language interaction profile across urban and rural schools

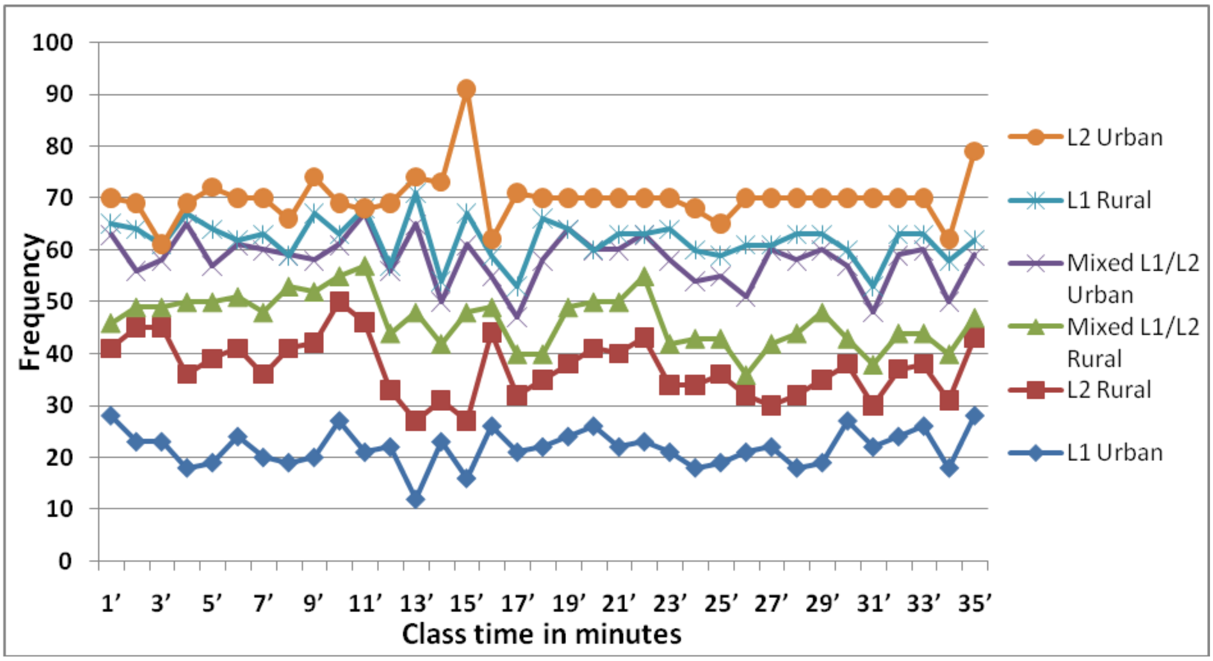

Figure 3: Primary 3: Language interaction profile across urban and rural schools

The Science Teacher as a Barrier

The science teacher constitutes, in a number of ways, a barrier to the meaningful learning of science. The hindrance is not deliberate since the teacher is employed to facilitate learning. These hindrances are manifested in the poor preparation of science teachers, low level of motivation and high level of stress in the work environment, impacting negatively on instructional delivery (Okebukola & Jegede, 1989; Jegede, Naidoo & Okebukola, 1996). The findings of our studies as summarised in Table 1 presents the factors which stress Nigerian teachers surveyed in 1989 and 2011.

Table 1: Mean Scores and Rank Order of Stress Factors

Students characteristics

S/No.	Prediction	Mean	Rank Order
1.	Poor attitude of students to science lessons	1.391	6
2.	Unruly and disruptive behaviour of students	1.218	7
3.	Breakage of/damage to expensive lab equipment	1.192	20
4.	Poor performance in science examinations	1.187	22
5.	Many science students do not behave like young scientists	1.180	23
6.	Failure of students to do assignments	1.196	19
7.	Students who look blank in science classes	1.200	17
8.	Students not coming to class with necessary materials	1.171	24

Teachers characteristics

S/No.	Prediction	Mean	Rank Order
9.	Having to teach a science subject one is not trained for	1.429	4
10.	Having to cope with the demands of new curricula	1.401	5
11.	Fear of getting injured as a result of lab accidents	1.192	20
12.	Lack of interest in teaching as a profession	1.163	25
13.	Difficulty in completing the syllabus in the time available	1.506	3
14.	Having to cope with teaching difficult topics	1.583	2
15.	Having to teach students who are not motivated to learn Science	1.286	9
16.	Not enough time to complete lesson preparation and marking	1.151	26
17.	Having to cover lessons for absent teachers	1.143	28
18.	Insufficient time to deal with private matters	1.151	26

School environment

S/No.	Prediction	Mean	Rank Order
19.	Difficulty in obtaining science teaching equipment	1.621	1
20.	Lack/inadequacy of laboratory support personnel	1.213	10
21.	No colleagues to consult on science teaching problems	1.126	29
22.	Large science classes	1.318	7
23.	Noise and other disturbances from neighbouring classrooms	1.105	30
24.	Lack of classroom space for group work	1.068	31
25.	Non-supportive role of other teachers towards science teaching	1.053	32
26.	School environment not having location for field work	0.002	33
27.	Pace of the school day is too fast	0.801	40

Administrative procedure

S/No.	Prediction	Mean	Rank Order
28.	Inadequate disciplinary policy of the school	0.966	34
29.	Having to comply with decisions made without consulting teachers	0.929	35
30.	Having to cope with non-teaching delegated duties	0.801	36
31.	Principal's reluctance to reprimand misbehaving students	1.200	17
32.	Assignment to classes not preferred	1.201	15
33.	Principal's reluctance to deal with difficult parents	0.843	37
34.	Unfavourable school time-table	1.201	15
35.	Having to cope with policies that are not supportive of science teaching	1.206	11

Conditions of Service

S/No.	Prediction	Mean	Rank Order
36.	Lack of opportunities for professional improvement	1.206	11
37.	Unattractive salary	0.821	38
38.	Delay in promotion	0.806	39
39.	Lack of opportunity to experiment with new ideas	1.206	11
40.	Lack of incentives and rewards for hard work	1.206	11

Other Barriers

Okebukola (1986f; 1987; 2011) document other indirect barriers to meaningful learning of science that are related to the home, government and examination bodies. With regard to the home, imposition by parents of science subjects on children in spite of poor aptitude for science; non-monitoring at home of students' progress in science; inadequate provision in many homes for the educational needs of students in science and craze for careers in business and banking rather than for science and technology-related courses are some of these barriers. With regard to government, two barriers which are frequently referenced are lip service paid to science education as evidenced by gross underfunding and inadequate reward for excellence in science teaching and learning (better reward system is applied to footballers and musicians). Overloaded curriculum/examination syllabus in science has been identified as barrier related to examination bodies.

After this summary of obstacles to meaningful learning of science, we should now examine how the major barriers can be scaled through the use of metacognitive instructional strategies. It should be mentioned that some of the barriers highlighted above such as issues relating to science teacher stress, home, government and examination-body induced barriers are beyond the scope of this paper for remediation as they have been addressed elsewhere (Okebukola, 2011).

Breaking the Barriers

The intention of this paper is not to suggest strategies that can be deployed to merely improve students' performance in science ostensibly through rote learning, but to review strategies that our studies and others have confirmed "in real life" to move students from rote to meaningful learning. We shall present highlights of our findings from 1986 to 2012 which consistently demonstrate the potency of the strategies over time. The emerging strategies can be collectively labelled active-learning and they include cooperative learning, concept mapping, use of analogies and more recently, use of computer-assisted methods. We will also describe some socio-culturally relevant methods that we have applied successfully in African schools. The common elements in these strategies are that concepts learned are at the deep level and transfer as well as problem-solving is attained by the student. The three emerging conclusions are that (a) students learn more deeply when they can apply concepts taught in class to real-world problems, and when they to take part in projects that require sustained engagement and collaboration; (b) active learning strategies have a more significant impact on meaningful learning than any other variable, including student background and prior achievement; and (c) students are most successful when they are taught how to learn as well as what to learn.

We fired the first shot at the barriers to meaningful learning of science using the cooperative-learning strategy as "our high-velocity bullet". An earlier survey (Bajah & Okebukola, 1980) and a scan of the literature showed that the laboratories especially of our public schools are ill-equipped and do not afford students opportunities for individual practical work. What do you have in the biology laboratory? A few weather-beaten microscopes, a litter of awful smelling preserved specimens, a few hand lenses, to be used by 200+ senior secondary students, many of whom have been compelled by certificate requirements to do biology. Walk into the chemistry laboratory and you will see a few glassware including a handful of burettes and near-empty reagent bottles. Physics? Worse still. At the primary level, the nature corner with a few odds and ends make up the laboratory. At the university level, many obsolete equipment adorn the laboratories. In these settings, meaningful learning takes a dive out of the window.

The idea behind the cooperative-learning strategy is to disallow meaningful learning from "jumping out of the window" in spite of the constraints of facilities. Instead of the science teacher refusing to do practical work because equipment cannot go round his/her army of students, the few items of equipment can be used optimally by groups (if you like, platoons) of students on cooperative-learning basis. Common sense? Yes! But where is the empirical proof of efficacy? We provided this through a series of experiments which we started in 1980. The first in the series of studies (Okebukola & Ogunniyi, 1983), compared the performance in practical skills, cognitive achievement and attitude towards biology of

1,047 students in three groups – cooperative (CP), competitive (CM) and individualistic (IN). Our results were mixed, some of which ran "against the run of play" in the science education literature but which finally earned publication space in the *Journal of Research in Science Teaching*. We found that students in the cooperative-learning group performed best of all in cognitive achievement. They also had the greatest positive attitude change. On practical skills, the competitive group emerged superior.

Having established empirically the potency of the CP strategy, we decided to dig in further within this terrain. Our second and third series of experiments (Okebukola, 1984; Okebukola, 1986a: 1986b; 1986c; 1986d; 1986e; 1986f) focused on determining which variant of cooperative learning is most predisposing to achievement. We tried the Jigsaw, TGT, and STAD and compared with CP+CM, our emerging model. We found CP+CM to be superior (Okebukola, 1985b).

We rounded up this phase of our work by examining the critical group size and the mix of members within the CP+CM setting. Our findings on the critical group size, that is, how many students should the science teacher allow in a cooperative-learning group for best effect, have remained inconclusive. More work would, therefore, be needed in this area. On the mix of students in the group, we have been able to gather a respectable corpus of evidence from our studies (e.g. Okebukola, 1984; 1985a; 1985b) and from the literature (e.g. Johnson & Johnson, 1994; Gillies & Boyle, 2010) that high; average and low ability students in the proportion of 20%; 60% and 20% is ideal with a mixed-sex colouration. In sum, our studies converge in suggesting that if meaningful learning of science is the goal in an environment with shortage of equipment and materials, the CP+CM strategy displaying intra-group cooperation with inter-group competition using mixed-ability and mixed-sex groups is potent.

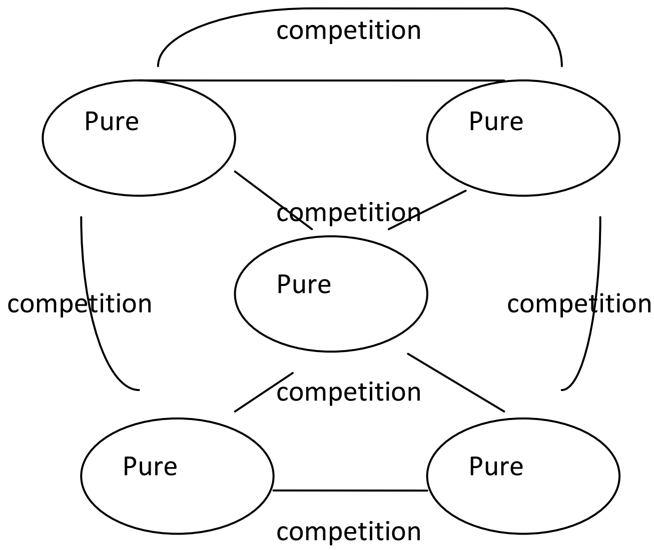

Fig. 4 Intragroup Cooperation with Intergroup Competition

Let us take another tool/strategy- concept mapping for bolstering meaningful meaning. Concept mapping is one of the three metacognitive tools that was invented by the

Cornell school of researchers in the early 70s. The others are vee-mapping and concept-circle diagramming. We have had the opportunity of working with Professor Joe Novak, the leader of the team that invented concept mapping and also Professor Jim Wandersee who developed the vee-mapping technique.

Concept mapping is a metalearning strategy based on the Ausubel-Novak-Gowin theory of meaningful learning. It relates directly to such theoretical principles as prior knowledge, subsumption, progressive differentiation, cognitive bridging, and integrative reconciliation. Basic to making a concept map is the ability of the mapper to identify and relate its salient concepts to a general, superordinate concept. That requires an understanding of what constitutes a science concept. Concepts may be defined as regularities in objects or events designated by some label, usually a term. Whether a process (e.g. precipitation), a procedure (e.g. titration), or a product (e.g. carbohydrate), concepts are what we think with in science. Concepts can be connected with linking words to form propositions (e.g. turtles are classified as reptiles, sucrose tastes sweet, ontogeny recapitulates phylogeny). Therefore, a concept map may be defined as ".... a schematic device for representing a set of concept meanings embedded in a framework of propositions" (Novak & Gowin, 1984; Novak, 2002).

Concept maps can be constructed by students from texts or after class discussions/lecture. It involves listing the main ideas/concepts and words and arranging these in a hierarchy. The most general, abstract and most inclusive (superordinate) concepts are lower down in the hierarchy. This array of concepts is connected by lines or arrows carrying labels in a propositional or prepositional form. At the terminus of each branch may be found examples of the terminal concept. A finished concept map is analogous to a road map with every concept depending on others for meaning.

In constructing concept maps, students note the keywords/concepts, phrases or ideas that are used during the lesson or read in a text; arrange the concepts and main ideas in a hierarchy from the most general most inclusive and abstract (superordinate) to the most specific and concrete (subordinate); draw circles or eclipses around the concepts; connect the concepts (in circle) by means of lines or arrows accompanied by linking words so that each branch of map can be read from the top down; provide examples, if possible, at the terminus of each branch; cross-link hierarchies or branches of the map where appropriate.

Our exploration of the potency of concept maps in breaking barriers to meaningful learning of science began in 1986. Using two groups of senior secondary biology students, we found the concept mapping group, after five weeks of post-familiarisation treatment, to significantly outperform the control group that did not have the concept-mapping experience in a test of meaningful learning of ecology and genetics - two concepts that are perceived to be most difficult by many SS biology students in Nigeria (Okebukola, 1991). Replication of this study in two other sites produced results that conformed our initial findings. The instruments that we developed for the study on concept mapping, genetics and ecology have been adapted for use by researchers in the UK, USA, China, South Korea and Nigeria. The attitude of science teachers to the strategies has been largely positive (Okebukola & Jegede, 1992; Okebukola, 1993; 2011).

We continued with further exploration of the potency of the concept-mapping technique in 1989 and 1990. We found that the strategy enhanced problem-solving skills in science (Okebukola, 1991). Our major contribution turned out to be the use of the concept-mapping technique in a cooperative-learning setting. Our data (further confirmed in 2011) showed that individual concept mappers performed less well than students who mapped cooperatively.

Our third technique was the use of analogies. Teachers use analogies to build conceptual bridges between what is familiar (an analog concept) and what is new (a target concept). The Teaching With Analogies Model includes six steps: (1) Introduce the target concept, (2) Review the analog concept, (3) Identify relevant features of the target and analog, (4) Map similarities, (5) Indicate where the analogy breaks down, and (6) Draw conclusions. Analogies can be powerful teaching tools because they can make new material intelligible to students by comparing it to material that is already familiar. It is clear, though, that not all analogies are good and that not all .good. analogies are useful to all students (Orgill & Bodner, 2003). The analogies group in our studies over a 20-year period performed significantly better than the control (see for example Okebukola, 1991 and Okebukola & Salawu, 2011). We used culturally-familiar analogies whenever possible in order to connect science concepts to the students' real-world experiences. Occasionally bringing culturally familiar examples into the science classroom makes the learning environment hospitable for all students. Our studies and those of several others have confirmed the potency of use of analogies (and metaphors) in bolstering meaningful learning of science concepts. Nierbert, Marsch, & Treagust (2012) reanalysed 199 instructional metaphors and analogies on the basis of a metaphor analysis, and showed that it takes more than making a connection to everyday life to communicate science fruitfully. They showed that “good instructional metaphors and analogies need embodied sources. These embodied sources are everyday experiences conceptualised in, for example, schemata such as containers, paths, balances, and up and down”.

A superordinate framework for many of these methods is to assign them as constructivist-oriented strategies. This theoretical framework holds that learning always builds upon knowledge that a student already knows. Because all learning is filtered through pre-existing schemata, constructivists suggest that learning is more effective when a student is actively engaged in the learning process rather than attempting to receive knowledge passively. The characteristics of a constructivist classroom are the learners are actively involved; the environment is democratic; the activities are interactive and student-centered; the teacher facilitates a process of learning in which students are encouraged to be responsible and autonomous; goals and objectives are derived by the student or in negotiation with the teacher or system; teachers serve in the role of guides, monitors, coaches, tutors and facilitators; activities, opportunities, tools and environments are provided to encourage metacognition, knowledge construction and not reproduction is emphasized; learner's previous knowledge constructions, beliefs and attitudes are considered in the knowledge construction process; and problem-solving, higher-order thinking skills and deep understanding are emphasized. A number of researchers in Nigeria have reservations about the use of constructivist-driven strategies on account of the difficult with covering examination syllabus to which many school authorities, parents and students subscribe (see for example Nwagbo & Obiekwe, 2010).

As the presence of technology increases in science classrooms, we explored the use of the computer in fostering student learning. Our studies are indicative of positive effect (Jegede, Okebukola & Ajewole, 1991a; 1991b; Okebukola, 2011).We are currently exploring the use of social media to promote the teaching and learning of science.

Conclusion

In this paper, we reviewed major barriers to meaningful learning of science and undertook a catalogue of strategies that our studies have proved potent in breaking down such barriers. The sum total of our efforts is that active learning should prevail in science classes and in a language that the learner is most familiar.

When students enter the classroom, they bring along with them a complex set of assumptions about the way the natural world works. These children then will struggle to fit whatever new phenomena they encounter through science lessons into their existing understanding. Many times, a child's existing knowledge base - which typically includes many inaccuracies - and his or her new experiences will conflict. As the child's mind gamely tries to force a square peg into a round hole, the peg - a valid science concept - may become damaged. Researchers have termed these damaged understandings "naive conceptions," "misconceptions," or "preconceptions". Science teachers should determine students' levels of scientific understanding and assist them in learning more science. Since we now know people do not learn at the same rate, why do we continue to expect all students to understand the same concepts in the same depth at the same time?

In this paper, we have reported studies conducted mainly in Nigeria. We have high hopes that our research network will extend to other countries in Africa so that cross-regional patterns can begin to emerge on how students learn science meaningfully. It is hoped that this conference will avail us an opportunity to enter into such networks with colleagues from the southern Africa sub-region.

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