

Global Best Practices in the Teaching and Learning of Science

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Abstract

Researchers and stakeholders have expressed much concern about the apparent fall of science education at all levels. Quite a number of factors were considered as being responsible but chief among these factors has been the use of inappropriate, ineffective teaching methodology. And it is noteworthy that, for any innovation in the science classroom, the teacher is the key. This paper discussed best practices in the teaching and learning of science as an inherent part of the curriculum with emphasis on pedagogical content knowledge (PCK) of science teachers and highlighted innovations that support best practices in teaching and learning of science. It would appear that what is missing is neither a theoretical base nor a range of methods and examples of best practice. The problem rather seems to be a failure to implement or put in practice what is already known. The paper further suggested potential areas (though not exhaustive) for innovation as best practices in teaching and learning science.

Introduction

Researchers and stakeholders have expressed much concern about the apparent fall in the standard of science education at both the secondary school and tertiary levels of education in Nigeria. For instance, Nwosu & Okeke (1995), Madu (2004), Okebukola (2005), working separately, have lamented on the fall in the standard of science teaching in Nigeria. Nwagbo (2001) identified a number of factors obstructing students' understanding and achievement in the science subjects. Chief among these factors was the use of inappropriate and ineffective teaching methodology. Oludipe (2004) noted that a major defect in our system of education is that science is presented dogmatically in most schools as series of disjointed facts and concepts which students find difficult to relate to the real world.

It is well recognised that for any innovation in the science classroom, the teacher is the key (Eilks *et al.*, 2004). That is why research on science teachers' thinking and actions became one of the most rapidly expanding areas for science education research (De Jong, 2007) and several conferences have focused exclusively on this field in recent years (Eilks & Ralle, 2006). For science teacher education in Nigeria to survive in a new, globally competitive world, today's learners will need creativity, problem-solving abilities, a passion for learning, a dedicated work ethic and lifelong learning opportunities. Students can develop these abilities through instruction based on Best Practice teaching strategies.

Best practices are an inherent part of a curriculum that exemplifies the connection and relevance identified in educational research. They interject rigour into the curriculum by developing thinking and problem-solving skills through integration and active learning. Relationships are built through opportunities for communication and teamwork. Best practices are applicable to all levels of science teaching and learning, which also provide the building blocks for instruction. Best practices motivate, engage and prompt students to learn and achieve. Students who receive a balanced curriculum and possess the knowledge, skills and abilities to transfer and connect ideas and concepts across disciplines will be successful as measured by standardised tests and other indicators of students' success. Four best practices for teachers include: teaching a balanced curriculum, teaching an integrated curriculum, differentiating instruction to meet individual student's needs and providing active learning opportunities for students to internalise learning.

Theoretical Frameworks

Teacher Education is currently undergoing a period of unprecedented change across the world and Nigeria cannot be an exception. The drivers for this change include a theoretical re-start on domain-specific research in teachers' knowledge base and experiences which refer us back to Shulman's idea of Pedagogical Content

Knowledge (PCK) from the late 1980s (Shulman, 1986, 1987) and the impact of developing science and technology.

Shulman defined PCK as:

...that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding (Shulman, 1987:8).

While *content knowledge* refers to one's understanding of the subject matter, *pedagogical knowledge* refers to one's understanding of teaching and learning processes independent of subject matter; *pedagogical content knowledge* refers to knowledge about the teaching and learning of particular subject matter that takes into account the particular learning demands inherent in the subject matter.

By definition, PCK is subject- and domain-specific (Shulman, 1986; Shulman, 1987; Bucat, 2004). This is clear because a teacher does not always use the same instructional strategy. He or she adapts the approach for each specific situation according to the learners and to the content:

The outstanding teacher is not simply a 'teacher', but rather a 'history teacher', a 'chemistry teacher', or an 'English teacher'. While in some sense there are generic teaching skills, many of the pedagogical skills of the outstanding teacher are content-specific. Beginning teachers need to learn not just 'how to teach', but rather 'how to teach electricity', 'how to teach world history', or 'how to teach fractions' (Geddis, 1993).

A common view of PCK is that it is bound up – and recognisable – in a *teacher's approach* to teaching a particular content. To create such an approach, a *transformation* of the Subject Matter Knowledge (SMK) is necessary (Geddis, 1993; Van Driel *et al.*, 1998; Bucat, 2004). The use of scientific models is a good illustration of the focus of our study. Four years ago, using a very holistic approach to the nature of science, Taber (2008) discussed where the teacher comes into such transformational processes. Whereas the curriculum developer adopts a scientific or historical model into a curriculum model, the teacher is forced to make a second adoption of the curriculum model into a teaching model. The latter step is done on the basis of his beliefs and PCK, in other words, how to best explain the curriculum model to his individual learners under the circumstances of framing the lesson (De Jong & Taber, 2007). For the transformational step, the teacher uses his knowledge about common learning difficulties and alternative conceptions of students, his knowledge about representations of the subject matter for teaching and about instructional strategies incorporating, experiments, physical models, media and available materials (Van Driel *et al.*, 1998; Magnusson *et al.*, 1999).

Innovative Methods (Best Practices) that Support Teaching And Learning of Science(s)

Progressing from information transfer towards constructivist learning

The practice of 'lecturing' is prevalent in our schools, colleges and universities. The word 'lecture' literally means reading a book in front of others. This method of teaching was not chosen on grounds of pedagogy. It was rather a practical concession to the need for distributing information at a time when books were both rare and expensive. Over the years, times have changed and books are now readily available at reasonable prices. That notwithstanding, lecturing still remains a major component of the vast majority of science teaching programmes at all levels. At its worst, this still amounts to little more than a teacher or lecturer reading a prepared note in front of students. This approach has continued to dominate school science teaching throughout the twentieth century, which consists essentially a simple process of information transfer, involving a quite naïve teacher-centered paradigm amounting to little more than a teacher showering knowledge over the students, who were merely required to absorb this information and remember it.

It is this teacher-centered approach that many in-service and pre-service science teachers still bring into teaching with them, believing that they have knowledge to impart and that the better they teach, the better their students will learn. All too often, however, when we start to mark examination scripts, we discover that what we thought we had taught and what our students have actually learned are quite different. Our natural response is then to try to teach better. What we often find out is that, the better we teach, the better our students like our teaching, but not, the better they learn. What we have failed to realise is that, knowledge cannot be transferred intact from the mind of one person to the mind of another (Bodner, 1986). Information may be transferred but meaningfulness and understanding can only be constructed in the mind of each individual learner (Wittrock, 1989), which is in line with the central idea of constructivist learning theory (Ausubel, 1968). Meaningful learning requires the integration of incoming 'bytes' or piece of information with knowledge already possessed by an individual. The subsequent interpretation placed on this new information will depend largely on what the learner already knows (Ausubel, 1968).

Progressing from teacher-centered teaching towards student-centered learning

The belief in the efficacy of the information transfer method, as well as the rote and drill approach in lab courses and seminars, has been particularly resistant to

change, probably because it actually appears to work. After all, it is the students who have been most successful in spite of this approach who have tended to form the next generation of science teachers and lecturers. Not surprisingly, these students tend to believe that as the traditional teacher-centered approach has worked for them, it should also be the appropriate way for them to teach future students (Bandura, 1986) and such beliefs have remained hard to change in the absence of compelling evidence supporting the efficacy of alternative models (Hewson *et al.*, 1999).

Deficiencies in traditional teacher-centered approaches are now beginning to be recognised. Problems include the fact that we are not always able to explain everything fully or even comprehensibly to others. Our students, in turn, may often fail to listen and follow with sufficient care and attention or even on occasion, may lack the necessary cognitive ability or previous knowledge to permit the desired interpretation of newly acquired information to occur. The underlying problem, however, is surely that learning is much more complex than merely listening, memorising and reproducing. As George Bodner opined over twenty five years ago, "Teaching and learning are not synonymous; it is possible to teach and to teach well without having the students learn" (Bodner, 1986: 873).

If we wish to support and encourage our students to learn better, we must first seek to understand how students learn and then adapt our teaching to support this process. Learning to teach is a process that never ends. If we are to improve as teachers, we must continually reflect on the effects of our teaching on our students' learning and keep amending our practice appropriately. A scholar said good teaching involves striving continually to learn about students' understanding and the effects of teaching on it.

So, what do we need to do to ensure that our teaching will encourage students to learn? Learning, like teaching, is an active process; so if we wish to promote more effective learning, we need to focus less on what we, as teachers, should be doing and more on what we should expect our students to be doing. It, therefore, seems obvious that learning environments that allow for and provoke activity and cognitive engagement are necessary (Bodner, 1986). For example, problem-based approaches, which require consideration of a problem and the subject matter behind it and challenge students' understanding of this material, can clearly promote active learning (Anderson, 2007). However, merely solving a problem may not always provide a meaningful learning experience.

Deeper learning is likely to be promoted where students are required to work in groups to solve meaningful problems. Here, students can be encouraged to exchange suggestions for possible solutions to problems and as a result will tend to clarify their own thinking on the issues in question. The principles of learning through articulating one's own thoughts and of being encultured into a scientific

community by learning the language and style of scientific argumentation are central to a constructivist philosophy as described by Hodson & Hodson (1998). In this context, classical, teacher-centered forms of learning are not adequate (Zoller, 1993). Of course, students' perceptions of their own learning progress may also be flawed. Many students, having failed chemistry examinations, when asked what went wrong, have replied that they had expected to do better, as they had understood it when it was covered in class (Byers, 2001). They had not of course; they had merely been able to follow it.

Research by Katona in (1940) identified lecturers working examples on a blackboard as something that does not promote good learning (quoted by Herron, 1996: 99). This might suggest that where lectures become too user-friendly and students feel too comfortable with material being presented, they are less inclined to think about it and hence fail to develop the real understanding that will be needed for successful future application (Zoller, 1993). Just like passengers in a car who sees no difficulty with a journey because the driver knows the way, they may often, nevertheless, be incapable of making the journey on their own at some future time.

Best practices in science teaching and learning advocate collaborative learning, which represents a significant shift away from the typical teacher-centered or lecturer-centered milieu in science classrooms. In collaborative classrooms, the teaching, listening and note-taking process may not disappear entirely but goes alongside other processes that are based on students' discussion and active work with the course material. Teachers who use collaborative learning approaches tend to think of themselves less as expert transmitters of knowledge to students and more as expert designers of intellectual experiences for students-as coaches or mid-wives of a more emergent learning process.

The role of the teacher can be seen to being transformed from one of primary "dispenser" of knowledge to one of being a facilitator of learning. This is a more demanding role in many ways since the teacher now provides information in the context of a rich learning environment, in which the student is an active learner. For instance, rather than the teacher telling the students what they are to learn, the teacher sets up an environment where the students can be active in acquiring knowledge, mainly through the process of experimentation and discourse, thereby placing more emphasis on the recommended approach, rather than the traditional method (Olorundare, 2011) (Table 1).

Table 1: Shifts in teaching that lead to effective learning

Less emphasis on	More emphasis on
Rigidly following curriculum	Selecting and adapting curriculum
Focusing on students' acquisition of information	Focusing on student understanding and use of scientific knowledge and inquiry processes
Presenting scientific knowledge through lecture, text and demonstration	Guiding students in active and extended scientific inquiry disadvantaged caused by non-availability of resources and funds
Teaching students for factual information at the end of the unit or chapter	Continuously assessing students' understanding
Maintaining responsibility and authority	Sharing responsibility for learning with students, i.e. cooperativeness
Supporting competition	Supporting a classroom community built on cooperation, shared responsibility and respect

Focusing on the professional development of science teachers

To teach well, it is obviously necessary for a teacher to possess a good knowledge of the subject matter to be taught (the what), in the case of the sciences. Nevertheless, a good teacher must also possess a well-developed understanding of how people learn (the how), pedagogy, in general and in a domain-specific form. This has long been appreciated in primary and secondary levels of science education, where qualifications in both a discipline and general pedagogy have been considered prerequisites even to apply for a job as a teacher in Nigeria.

Although, governments have started to realise that teachers and lecturers need training on how to teach effectively, in most cases, training, where provided, tends to be offered only after employment as a teacher has commenced; it is usually rather generic in nature and often appears to be regarded as a chore or at best, a distraction by new lecturers under increasing pressure to rapidly develop reputable research profiles. We suggest that the benefits of learning only about general pedagogy are somewhat limited. A science teacher or science educator needs to know specifically about how people learn science. There is, therefore, a need to provide subject-specific examples and methods to help teachers new to the teaching of a particular topic, to understand how best to set about improving their own

teaching practices with respect to a specific domain. It is necessary to appreciate learning difficulties peculiar to science students, such as alternative frameworks or misconceptions and how best to overcome them, using explanations, examples, problems, models, experiments, etc. Over the past 25 years, Pedagogical Content Knowledge (PCK) (Shulman, 1986; Bucat, 2004) has gradually come to be recognised as a third essential element of a teacher's required knowledge base. PCK includes domain specific knowledge of how students learn particular topics, details of potential approaches of how to teach these topics effectively and appropriate methods of assessment to evaluate the quality of the learning in the specified domain (Magnusson *et al.*, 1999).

Innovating to enhance science learning in schools

Based on the view that education should be active, demanding and cooperative, Chickering & Gamson (1987) asserted that good practice in students' education:

1. encourages student-faculty contact;
2. encourages cooperation among students;
3. encourages active learning;
4. gives prompt feedback;
5. emphasises time on task;
6. communicates high expectations; and
7. respects diverse talents and ways of learning.

Sorcinielli (1991) discussed the efficacy of these seven principles in supporting meaningful learning in science classes. He opined that while didactic lectures can undoubtedly be inspirational, they however demote the learner to a very passive role and clearly embrace none of the above principles. We can thus contend that a bad lecture, providing it is followed by outside reading or peer group discussions to try to make sense of the content, represents a much richer learning experience than a good lecture, whatever that may be, with little student follow-up (Cooper, 1995).

Recent attempts to increase student interactivity in lectures (Byers, 2001; Smith, 2006), have enjoyed only partial success because of the difficulties of involving all students in large classes and also on account of the reluctance of many students to become involved in case they embarrass themselves in front of their peers. However, the recent availability of efficient, reliable and easy-to-use electronic voting systems ('Clickers', which have been described by many names in the literature: Audience Paced Feedback (APF), Classroom Communication Systems (CCS), Personal Response Systems (PRS), Electronic Voting Systems

(EVS), Student Response Systems (SRS), Audience Response Systems (ARS), now offers the promise of making classes more interactive for all (Bates & Howie, 2006).

Today's learners, according to a research, are very comfortable with the technology involved and appear to like and be motivated by the approach; and the controlled use of electronic voting systems readily embraces at least four {(2), (3), (4) and (6)} of Chickering and Gamson's seven principles. It has been argued that to be effective, any educational change needs to be introduced relatively slowly, so as to enable students – as well as the teacher – to become accustomed to the demands associated with a novel approach. 'Clickers' are not magic wands; care and thought will be needed if they are to be used effectively. This is only one example of how practice may be improved through relatively small innovations. There are many other innovations that have been tested and shown to have the potential to improve learning in the domains of both knowledge and process-oriented skills. In all cases, however, it is clear that we must move the emphasis from teaching to learning (Barr & Tagg, 1995).

Potential Areas for Innovations in the Teaching and Learning of Science

The following areas (though not exhaustive) have been identified as potential areas that require innovation for any developing nation or whoever wishes to achieve the goals for science teaching, such goals that will translate into best practices in the teaching and learning of science:

Practical works or hands-on activities

Practical work should be regarded as an essential component of science teaching and learning. Best practices should consider how best to improve the learning experiences offered by laboratory work and identified the importance of starting with a clear view of the learning outcomes expected for each experiment. It is suggested that lab work must move away from merely asking students to blindly follow procedures, which though helpful in developing their manipulative skills, will do little to stimulate cognitive activity or challenge their curiosity. It has been asserted in a research that a number of strategies are available to introduce more discovery and inquiry type assignments into laboratory programmes in order to promote better student learning. It is stressed that in general, it is not necessary to change the experiments themselves but only the way in which they are used, to offer considerable improvements. It is recommended that students be allowed more freedom to develop their own strategies and pathways for experimentation. Such an approach has been shown by some scholars to be successful in both secondary and higher levels of learning. It is also evident that laboratory work can act as a

driver for learning in topical areas such as Health and Safety and Green Chemistry (Ranke *et al.*, 2008).

Innovative assessment that promote meaningful learning

- Innovative approaches to teaching and learning of sciences must be supported by appropriate innovative forms of assessment. This is because education involves far more than mere rote learning of facts; the nurturing of genuine understanding and development of personal and professional transferable skills are also necessary. This means that we need forms of assessment able to assess not only factual knowledge but also understanding and a broad spectrum of competencies (Race, 2009). Exclusive reliance on traditional unseen written exams will, therefore, rarely be adequate and there is a need to reflect on the implications of our assessment methods on both teaching and learning. A number of benefits associated with a change from closed-book, time limited, formal examinations towards a continuous, open book assessment approach have been reported in the literature (Eilertsen & Valdermo, 2000). The case for using a wider variety of assessment techniques, tailored to promote specific desired learning outcomes, such as the development of higher order cognitive skills, is made. A range of different methods and approaches to assessment are already available and seem only waiting to be applied in higher level science education.

Cooperative learning

- Cooperative learning, which is founded on constructivism, is one of the methods used to foster active students' participation during the learning process. When students work in cooperative groups, they more frequently use higher levels of reasoning and critical thinking skills to create new ideas and solutions compared to when they work in competitive and individualistic situations. Researchers have indicated other benefits of cooperative learning as higher academic achievement, greater persistence through graduation, deeper understanding of learned material, better attention and less disruptive behaviour in class, lower level of anxiety and stress, more motivation to learn and achieve, positive attitudes to subject matter, higher self esteem (Johnson & Johnson, 1999). This shows that students achieve more, improve their social skills and increase their capacity to work productively together while working in cooperative learning environment.

Revitalising Teacher Education Preparation in Science as Best Practice

While the case for changing traditional approaches to science teaching in schools is very strong, teachers will surely need guidance and training if change is to be

implemented. This is why lifelong training of science teachers will be a good practice in the help being offered to in-service teachers to develop a modern and evidence-based approach to teaching sciences at all levels.

Science teachers must understand students' thinking and be familiar with appropriate learning strategies to support the meaningful learning of chemistry as well as related study skills. Science teachers must be taught how to improve and reflect on their own work. Teachers need more evidence-based information on how to promote their own learning as well as that of their pupils.

Considerable evidence exists on how we learn science; students must be provided with appropriate opportunities to investigate, explore and construct meaning for themselves. The present orientation of teacher-centered instruction should be deemphasised. Six principles have been identified to guide the development of exemplary pre-service (and in-service) science preparation. The six principles focus on three aspects of a comprehensive programme: (i) the content/process preparation (ii) pedagogy and (iii) the nature of human development and learning.

Teachers of science must focus on the intersection of these three areas in their preparation. Each component is affected by and in turn affects a larger context or milieu including (but not limited to other) issues such as gender, social ethics, students, laboratory materials, etc.

Principle 1

Every school teacher (and pre-service teacher) should experience the investigative nature of science. Although, didactic teaching has its place, it cannot impart an understanding of the investigative nature of science. The most effective investigative experiences begin with questions and problems that are generated by the learner.

Principle 2

Every prospective and practising teacher should have the classroom and laboratory experiences in the science field, e.g. Chemistry, Physics and Biology. Science should reflect what is known about understanding and meaning is acquired of the natural sciences. Besides, learners should have opportunities to construct meaning from activities and courses that focus on difficult topics.

Principle 3

Pre-service and in-service teachers should understand the interrelatedness of science disciplines and the connections between science and other areas of knowledge. For instance, solving problems that are rooted in scientific and technological arena

draws upon skills and knowledge that is multidisciplinary.

Principle 4

All prospective science teachers should learn scientific content and thinking processes in the context of contemporary relevant, personal and social issues/problems. Thinking processes learned in the classroom and laboratory must have the applications to the real world.

Principle 5

The need to have a sound understanding of the nature of learning and how it can be applied to the learning of science. Understanding includes the idea that science knowledge and skills are constructed in the mind of learners through direct experience and the idea that capacities related to learning are developmental and sequential.

Principle 6

The need to have several intense and extended clinical teaching experiences at a variety of grade levels in diverse socio-economic and cultural settings. Each experience should be guided/grounded in theory and pedagogical knowledge. Students tend to model the various ways in which they have been taught; hence, good science education is good teacher education.

Conclusion

It would appear that what is missing is neither a theoretical base nor a range of methods and examples of best practice. The problem rather seems to be a failure to implement or put in practice what is already known.

It is of utmost concern that, as effective teacher, you must have sound, thorough and strong background knowledge of what you are to teach and what you have to teach. This entails detailed preparation. It is also important to note that effectiveness in the teaching/learning enterprise cannot be realised if you, as a teacher, are weak and deficient in the subject matter to be taught. You have to know the subject matter. Are you knowledgeable enough to teach the topic effectively? What is your intellectual status on the topic under consideration?

Recommendations

- i. To properly convey a message, the individual concerned must have a good (not poor) understanding of the message. As a teacher, you ought to know

the subject matter better than your students, since you cannot teach effectively what you do not know. Consequently, effective teachers have to have a solid understanding of what they are expected to teach.

- ii. We would suggest that the area of Pedagogical Content Knowledge (PCK) has become an increasingly important part of training for science teachers. Therefore, science teachers must start to think of improving their knowledge of and competence in teaching, as much as they already consider developing their research skills, as an essential part of their continuing professional development.

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