TESSA secondary science: addressing the challenges facing science teacher-education in Sub-Saharan Africa

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Abstract

In recent years, access to primary education in Sub Saharan Africa (SSA) has improved. This is creating considerable pressure at secondary level where there is a shortage of school places and teachers. Furthermore, students' educational outcomes are poor and not, therefore, contributing to human capability development as much as they could.
TESSA Secondary Science, funded by The Waterloo Foundation, is a collaborative project, co-ordinated by The Open University with partners in Ghana, Kenya, Tanzania, Uganda and Zambia, designed to support the pre-service education of secondary science teachers.
This paper describes the project and identifies the key issues for implementation. We report on the pedagogical themes identified by the group and demonstrate how these will be exemplified in specific scientific contexts. We will be building on the learning from TESSA and will argue that, whilst significant challenges lie ahead, the approach that we have adopted has the potential to make a real contribution to the problems facing secondary teacher educators in science.

Key words: TESSA, secondary science, teacher education, pedagogy, backward mapping

Introduction

In recent years there have been considerable advances towards the achievement of Millenium Goal 2: universal primary education by 2015 (UNDP, 2011). Countries in Sub-Saharan Africa (SSA) that previously educated around 50% of primary aged children are now achieving 70-80%. This is creating considerable pressure at secondary level with a significant shortage of secondary school places in many countries and a shortage of secondary teachers (Verspoor, 2008). It has been suggested that secondary education in SSA does not contribute as effectively to human capability development as it should as student achievement is low. Indeed, strong performance in maths and science in particular, is associated with economic growth. There is therefore an urgent need for expansion of secondary education in terms of schools, resources and the number of teachers, and a focus on quality, particularly in science and mathematics. Collins and Gillies (2008) believe that the structure of the current system for training teachers will not allow for the necessary expansion. Secondary teacher training takes four years and involves subject knowledge development and pedagogic preparation. Criticisms of the programmes (Verspoor, 2008) include:

- an over-emphasis on theoretical studies which are not explicitly linked to practice;
- insufficient supervision and mentoring;
- the tendency of pre-service teachers to teach as they themselves were taught.

Collins and Gillies (2008) suggest that pre-service training needs to be accelerated with shorter periods of pre-service education and a greater emphasis on in-service training. They believe that pre-service programmes need to be re-designed with a greater emphasis on the practical application of the theory.
TESSA Secondary Science is a project that has been designed to begin to address some of these challenges. Building on the learning from the successful TESSA project, which has made available a bank of Open Educational Resources (OERs) designed to support teacher-learning in primary schools, we are in the process of producing resources to support the education of secondary science teachers. This is a collaborative project, funded by the Waterloo Foundation, with partners in Ghana, Tanzania, Kenya, Uganda and Zambia. Implementation in the first instance will be in pre-service education, and eventually we anticipate the resources being used with in-service teachers, seeking to up-grade their skills. In some of the countries in which we are working, there are increasing numbers of primary school teachers being asked to teach in the lower secondary school; these resources will be particularly relevant to that audience.

Introducing TESSA secondary science

Beliefs

In this section we will set out the principles underpinning the project, identify significant features of the secondary context that are influencing our work and explain how what we have learnt from the TESSA project so far is shaping the project.

TESSA Secondary Science (like the original TESSA project) is underpinned by the belief that active approaches to learning are likely to produce better outcomes for students than teacher-led lessons in which students are passive participants, and that it is the role of the teacher to support students in constructing understanding, taking into account prior knowledge and experience. Teachers are also considered to be 'learners' and teacher learning is conceptualised within the TESSA consortium as:

'.. being social, jointly constructed with pupils and peers; distributed, shared over the people, activities and artefacts within the environment; and situated, linked to the circumstances in which it occurs, the particular working practices and their associated ways of thinking'. (Wolfenden, 2008, p9).

We believe that this certainly applies to secondary pre-service teachers. Our own observations (Tanzania workshop, 2010) suggest that student teachers are being taught sound constructivist principles which recognise the importance of prior knowledge and good questioning techniques, the benefits of effective groupwork and the desirability of practical work in science, but that they find it difficult to apply these in practice and often view these techniques to be separate from their 'real' teaching. Constructivist approaches are rarely being modelled on teacher education courses, although they are certainly being talked about. It is clear, therefore, that a development directed at the secondary sector is not only timely but could make a real contribution in terms of developing good practice.

Whilst the underlying philosophy of TESSA secondary science mirrors what has gone before, there are three key differences between the primary and secondary contexts that we have taken in to consideration. Firstly, in all five countries, secondary teachers undergo formal training of up to four years – hence the emphasis on supporting pre-service teachers. During that time, they train as subject specialists, so there is a considerable emphasis on developing subject knowledge to an appropriate level. Secondly, when in school the pressures on teachers, afforded by the curriculum and the need for their students to perform well in formal examinations are considerable. We need to acknowledge this and be explicit in how we support teachers in dealing with these pressures. Thirdly, all pre-service secondary teachers undertake some school experience in the countries in which we are working. They will therefore have the opportunity to try out TESSA secondary science units and the support that they get in school will be crucial. Evidence suggests that this is variable, but could be very important in encouraging them to try out the activities. The development of peer-support networks would clearly be helpful and work in Ghana (MacBeath *et al*, 2010) to encourage headteachers to be more pro-active in providing pedagogical leadership could also prove to be significant.

TESSA secondary science will be targeted on pre-service teachers, although clearly the resources will also support in-service training and professional development. Indeed, in some of the countries in which we are working, primary teachers are increasingly being asked to teach in the lower secondary school, owing to an increase in the number of students and a shortage of trained secondary teachers; TESSA secondary science resources could support these teachers.

As well as taking into consideration the beliefs underpinning the TESSA approach and the secondary context, we also have the benefit of the learning from five years of development and research activity in nine African countries. Our own work, and the work of others (Brodie, 2002), suggests that successfully embracing curriculum change involves understanding both the 'form' and the 'substance' of the developments. Teachers will often follow the procedures that are advocated without effectively promoting learning. For example, they might divide the students into groups, yet still provide a great deal of guidance and instruction, or they might introduce artefacts and resources into the classroom, but not give the students the opportunity to interact with them on their own terms. We know from our experience that embracing the 'substance' of learner-centred approaches requires a new way of thinking, but that when this is achieved it can be hugely effective (TESSA case studies, 2010). Indeed, this is confirmed by others working in similar contexts. Petrides and Jime (2008) found that in developing OERs in a project in South Africa (Free High School Science Texts) success depended on

….instilling practices within the organization or project that imitate the very characteristics of the resources that OER projects serve to create and support (p1).

Clearly the modelling of the approaches that the resources seek to promote will be crucial to the success of TESSA Secondary science.

We also know that mediating the resources and helping teachers to build networks is important, and we have a number of different models for use that the partner institutions will be able to draw upon (Thakrar *et al*, 2009).

Over a number of years and projects, experience developing in TESSA suggests that intervention should start at the point of maximum impact; the classroom. The work of Richard Elmore on the concept of 'backward mapping' has been highly influential here (Elmore, 1980). He argues that solving problems in complex systems involves maximising discretion at the point where the problem is most immediate and 'the closer one is to the problem the greater is one's ability to influence it' (Elmore, 1980, 605). Formal organisational structures with a high degree of hierarchal control are not necessarily helpful and the more steps that are required for implementation, the less likely that a policy will be successful. This view of change has influenced the way in which we have tackled the project and our plans for implementation.

The Project

The Vice Chancellors of our partner institutions were invited to nominate a representative to lead the project in their institution; all the representatives are senior figures within their institutions with the ability to influence the curriculum and assessment regimes (see table 1).
This clearly has significant advantages in terms of implementation, but has the disadvantage that they are not always directly involved with the pre-service teachers. Each representative has since nominated a partner from their institution who is actively engaged in teaching pre-service teachers.
Insert table 1
At the start of any project it is sensible to re-iterate the fundamental beliefs and to establish a shared vision, based on those beliefs. We did this at the first workshop (Tanzania, November, 2010) by collectively defining our vision of an effective teacher of science at secondary level. This vision has provided the basis for all our work (see Figure 1); it reflects the shared commitment to the principles that underpin the TESSA approach, including the idea that the change should start at the point where the intervention is most needed – in the classroom.

Insert figure 1 here

Funds are available to develop 15 units - in the form of OERs - based on the TESSA template, supporting the secondary science curriculum. Clearly, complete coverage of the curriculum cannot be achieved and a significant challenge has been to select a focus for the units. We decided at an early stage that the units must be recognisable as physics, chemistry and biology, given the subject specialisation that characterises pre-service teacher education at secondary level (Verspoor, 2008).

Five pedagogical themes were identified, based on our collective vision of an effective teacher and it was decided to exemplify these themes once in each subject. Robust discussion and joint observations of two lessons informed the process, and kept us grounded in what is both desirable but possible. The pedagogical themes embody the agreed vision and the contexts in which they will be exemplified represent topics that are relevant to the curriculum in all five countries (table 2).

Insert table 2 here

Finally we agreed a list of 'approaches to teaching' (including effective questioning, group work, practical demonstration, investigation and debating) that we would like to see supported through these units.

The notion of classroom materials to support teacher learning is at the heart of the TESSA approach, but it is not new. Davis and Krajcik (2005) describe a project to produce 'educative curriculum materials' for use in secondary science teacher education in the USA. They describe a set of nine 'design heuristics' that should be used to design such materials, based on what they consider to be the important parts of a teacher's knowledge base. The nine design heuristics are organised around the important parts of a teacher's knowledge base, namely, subject knowledge, pedagogical content knowledge for specific topics and pedagogical content knowledge for disciplinary practices. They are based on the challenges that teachers face as identified through a review of the literature. The 'themes' underpinning the TESSA Secondary Science project are based on the collective experiences of teacher educators from five African countries and the UK, and our agreed vision of an effective secondary science teacher. Interestingly there is considerable overlap (see Table 3), which gives support to both the TESSA approach and the framework that they present.

Insert table 3

The theme identified in TESSA secondary science that does not seem to represented in the 'design heuristics' for educative curriculum materials is 'promoting problem-solving and creativity'. This theme emerged from discussions surrounding the need for teachers (particularly in Africa) to be resourceful and creative, and from the belief that the ability to solve problems and to be creative were skills and attributes that should be fostered in pupils through the curriculum. The three units within this theme will support the teacher in being creative and resourceful whilst developing these skills for their pupils. A clearer identification of the nature of science and what children should learn about it , has taken place in recent years (Osbourne et al, 2003; Bartholemew et al, 2004), which sees working scientifically as more than doing experiments. It is possible that Davis and Krajcik might include a heuristic based on promoting creativity if they were to revisit this work today.

Interestingly, Grossman *et al* (2009) argue that teacher education should be organised around a set of core practices based on pedagogies of enactment. In their model for teacher education, knowledge, skills and professional identity would be developed in the process of learning to practice. They suggest some 'core practices', which include *eliciting student thinking.* Their ideas on re-structuring teacher education courses are developed in the USA but are perhaps even more pertinent in the African context, where traditionally theory and practice are treated separately. We would argue that the TESSA Secondary Science units define a core set of practices through which knowledge, skills, and professional identity are developed in the process of learning to practice and as such will make an important contribution to teacher education. For example, in the units on 'probing students' understanding' through the activities, teachers are introduced to three techniques that will enable them to elicit understanding.

Through discussion, we agreed that the TESSA template would form the basis of our units, which means that each one has learning outcomes for the teacher, three case studies, three activities and up to six resources. The introduction and narrative speak to the teacher and provide a rationale for what we are asking them to do, hence supporting them in transferring the ideas to alternative contexts. Suitable activities and some case studies were agreed during the workshops and the writing and critical reading is currently taking place.

Comparison with TESSA Primary

Both TESSA and TESSA Secondary Science seek to raise achievement by supporting improvements in the quality of teaching. The resources are produced in Africa, by Africans, are written using a collaborative process, are in the form of OERs and will be versioned for individual countries. There are four key differences that have emerged as a result of transferring the TESSA approach to the secondary context.

Firstly, our target audience in the first instance is pre-service teachers. The evidence from TESSA is that implementation is successful when the units are effectively mediated (TESSA case studies). We believe that teacher educators are in a good position to mediate these resources and are in a position to build them into their courses. Our hope is that the newly qualified teachers leaving college will act as ambassadors for the TESSA approach and will encourage their colleagues to make use of the units. It is likely, however, that the units could also form the basis of professional development programmes for in-service training and we hope that eventually this will be the case.

Secondly, compared to the original project there are fewer units and curriculum coverage this therefore restricted. The introductions are similar, introducing the pedagogical approach, but the narrative focuses more explicitly on pedagogy and the rationale behind the activities and case studies, encouraging teachers to transfer the approaches to other contexts. It is likely that a particular student teacher or teacher will only access five of the units (depending on their subject specialism); the challenge is to encourage them to transfer their developing knowledge of pedagogy to other contexts.

Thirdly, a significant challenge facing all secondary science teachers is the size of the science curriculum and the emphasis on examination performance. Our preliminary research shows that young, recently qualified teachers understand the benefits of active approaches to learning but believe that they take too long and will prevent them from completing the course by the end of the year. The activities suggested in the units, therefore, are designed to be short so that they can be completed as part of the ‘normal’ teaching. Our hope is that over time, as their students become more used to being actively involved at least for part of the lesson, teachers will become more confident in adopting the pedagogical techniques and teaching approaches described.

Finally, there will be considerable overlap between the units within a particular theme. At secondary level, teachers tend to be specialised and as a result the units within the theme ‘probing students’ understanding’, for example, are similar. Some of the narrative overlaps and some of the resources will be the same. All three of the ‘making science practical’ units present a teacher demonstration, a ‘circus’ activity and an activity based on a class practical, so the narrative in physics is, to some extent, relevant in chemistry and biology.
Overall, however, the structure of the units will be similar with case studies being used to illustrate a range of teaching approaches and resources supporting specific activities, subject knowledge and pedagogy. The challenge will be to implement these units into the curriculum of pre-service courses.

Implementation

TESSA is based on a model of change described by Elmore (1980) in which the intervention takes place at the point where change is required, called backward mapping. As we have shown, this has influenced the project design, with the emphasis always being on what happens in the classroom; change is from the ‘bottom up’ rather than from the ‘top down’. Dyer (1999) demonstrates that many well-intentioned initiatives fail to make the desired impact and suggests that the concept of ‘backward mapping’ can also be used to plan for implementation by identifying the ‘key actors’ at each level in the process. We have used the work of Dyer, to analyse your own situation and to identify the key challenges and opportunities. Our analysis will be used to plan for implementation (Stutchbury, 2011). The teacher educators have emerged as the key players so during the second workshop (February 2011) we interviewed all the contributors in order to better understand their beliefs, backgrounds and working environments. We found much to be encouraged about and a real commitment to education as a force for change:

‘I want student teachers to realise that if we can change individuals then we can change Africa’.

'Science teaching should be relevant to the learner – we have so many problems we need to solve'.

The key is to ensure that the resources that we produce are integrated into teacher-education programmes and that they are effectively mediated by university lecturers. This is where a number of challenges will lie.
One teacher educator talked about modelling the techniques they want to see in use:

But as much as possible I try to get their own thinking before I even tell them what I think or what it should be. …. The teacher trainees when it comes to training methods, pedagogy, you also put them in that position, you give them activities to carry out. You want to see what they come up with. They should go through the experience themselves. Activities should not necessarily be always using apparatus or manipulating. But you can also have role play.

Another one remarked:
'I model in through my own teaching and tackle people who have doubts'

But some responses were less encouraging:

'*we lecture them on methods'*.

There will also be challenges in school as it is clear that there is no tradition of mentoring, very little (if any) specific training for mentors and considerable variation in interpretation in of the role. Supporting the pre-service teachers in schools will be difficult but important and it is hoped that through using the resources in school, student teachers may be able to influence the teachers with whom they are working.

It is clear that teacher educators are under pressure within their own institutions. They are autonomous and have the ability to influence the curriculum, but they face increasing pressures in terms of large class sizes and insufficient resources.

Our analysis suggests that the key challenges at this stage appear to be

- making the resources available within all the institutions, when internet connections are slow and unreliable, and printing can be expensive;

- persuading student teachers they do have time to run the activities described AND finish the syllabus;
- integrating the units into teacher education courses in such a way that they support teacher-learning through modelling the techniques that are being advocated;
- Finding a way of supporting pre-service teachers in their use of the units when they are in school.

Conclusion

As the number of students completing primary school increases, the need for expansion in the secondary sector is urgent. There is an acute shortage of secondary teachers in the Africa and the length of time taken to train them is unhelpful. Traditionally subject knowledge and pedagogy are taught separately, mainly through formal lectures to large groups. The materials that we are producing will offer a new approach with pedagogy being illustrated in particular scientific contexts. We are building on the learning from the original TESSA project yet have made adaptations which reflect this different context. The challenges are significant, but the opportunities in terms of building capacity, and fulfilling a need are considerable. We have demonstrated in this paper that we are also building on the work of others and hence the capacity of the TESSA consortium to contribute to collective learning about the nature of teacher education.

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Table 1: TESSA Secondary Science partner institutions

Country	**Institution**
Ghana	University of Education, Winneba
Kenya	Egerton University
Tanzania	Dar Es Salaam University College of Education (DUCE)
Uganda	Makerere University
UK	The Open University
Zambia	University of Zambia

The Effective Secondary Science Teacher – A vision to guide us

1. **Knowledge & Understanding**
   An effective teacher will have knowledge of:
   a) **SCIENCE – content; concepts children find difficult; the curriculum;**
   b) **PEDAGOGY – strategies to support learning in science**
   c) **LEARNING – how children learn, and how to take account of this**
   d) **ASSESSMENT – how to find out what children understand / have learned**
   e) **THE CHILD – social; cultural; personal (interests, home)**
   f) **MOTIVATION – how children are motivated or de-motivated**

2. **Attitudes; Values; Attributes**
   An effective teacher will have the following attributes:
   a) **PROFESSIONAL – be a good role model**
   b) **SELF-MOTIVATED – wanting to learn; seeks improvement**
   c) **RESPECTFUL – of children, parents, colleagues**
   d) **INQUIRER – takes risks; try things out; experiments;**
   e) **RESOURCEFUL – problem solver; creative; positive thinker, risk taker**

3. **Practices**
   An effective teacher will do the following things:
   a) **PREPARATION - planning & preparation will be careful and thorough**
   b) **BE INCLUSIVE - consider and involve all learners**
   c) **BE ENGAGING - Engage learners and engage WITH learners**
   d) **PROVIDE VARIETY - Use a variety of teaching approaches, strategies and resources**
   e) **ASSESS PROGRESS – using a variety of techniques**

4. **Skills**
   An effective teacher will have the following skills:
   a) **COMMUNICATION – listening; explaining; questioning**
   b) **MANAGEMENT – of learning, resources, learners, time, self**
   c) **SCIENCE SKILLS – practical skills of science**
   d) **MOTIVATIONAL - how to inspire, excite and promote interest in science**

Figure 1: The TESSA Secondary Science vision of an effective secondary science teacher

Table 2: Themes and contexts that form the titles for the 15 TESSA Secondary Science Units

Themes	Physics	Chemistry	Biology
Probing students' understanding	Properties of matter	Elements, mixtures and compounds	Classification and adaptation
Making science practical	Measurement	Acids, bases and salts	Transport
Making science relevant to real life	Pressure	Combustion	Respiration
Problem solving and creativity	Forces	Atomic structure and the periodic table	Nutrition
Dealing with challenging ideas in science	Electricity and magnestism	States of matter and particles	Cells

Table 3: A comparison of the design heuristics for educative curriculum materials as identified from the literature (Davis and Krajcik) and the TESSA Secondary science themes.

Design Heuristics	Themes of TESSA Secondary Science
Supporting teachers in engaging students with topic-specific scientific phenomena	Science lived – making science relevant to the everyday
Supporting teachers in anticipating, understanding and dealing with children's ideas about science	Probing childrens' understanding
Supporting teachers in engaging students in questions	
Supporting teachers in engaging students with collecting and analysing data	Making Science practical
Supporting teachers in engaging students with designing investigations	
Supporting teachers in engaging students in making explanations based on evidence	Dealing with challenging ideas in science
Supporting teachers in using scientific instructional representations	
Supporting teachers in promoting scientific communication	*These feature across all the themes through the resources that accompany each TESSA unit.*
Supporting teachers in the development of scientific knowledge	