Re-visioning Curriculum and Pedagogy in a University Science and Technology Education Setting

Case Studies Interrogating Socio-Scientific Issues

Overson Shumba, George Kasali, Yaki Namiluko, Beauty Choobe,
Gezile Mbewe, Moola Mutondo and Kenneth Maseka
The Copperbelt University, Kitwe, Zambia

Abstract

We present reflections on case studies in which a team of researchers and student researchers at the Copperbelt University in Zambia carried out real-world context investigations. The case studies involve estimating the greenhouse gas emissions associated with activities in the university, exploring agro-applications of biotechnologies, investigating chemical pollutants that are potential endocrine disruptors in the environment and in fish, and modelling how to mainstream the socio-scientific issues into curriculum and pedagogy for science educators and teachers. The analysis using the lenses of education for sustainable development (ESD) and 'learning as connection' lead to the suggestion of re-visioning curriculum and pedagogy. This re-visioning entails that the learning of the technical content of science subjects is balanced with a consideration of socio-scientific issues and ESD processes. Project-based learning provided the model for integrating the concepts and principles of ESD and 'learning as connection' into the curriculum and pedagogy.

Introduction

Over the past decade, the question of how education for sustainable development (ESD) contributes and/or re-defines quality and relevance of education has remained a critical concern for researchers and practitioners in southern Africa (Lotz-Sisitka, 2010; Lupele & Lotz-Sisitka, 2012). This concern for ESD and educational quality is important in higher education. For example, the Abuja Declaration on Sustainable Development in Africa seeks to transform the quality of learning and research beyond meeting academic and scientific objectives in higher education (Association of African Universities, 2009). The Association for Development of Education in Africa (ADEA, 2012) at its *Triennial on Education and Training in Africa* stressed the urgency of reorienting education to more effectively contribute towards creating sustainable societies. The Africa Union's Agenda 2063 is focussed on 'the Africa we want', envisioning a prosperous Africa based on inclusive growth and sustainable development where people have a high standard of living, quality of life, and well-being (Africa Union Commission, 2015). This vision will remain unachieved if the quality and relevance of African education systems is not re-visioned to mitigate the continued unsustainable exploitation of natural resources, construction, agriculture, and city and industrial development.

In the vision outlined in *The Africa We Want*, citizens of Africa are well educated and have skills underpinned by science, technology and innovations. The citizens, the ecosystems, and the entire African and global environments are healthy. Realising this vision will require strengthening science, technology, engineering and mathematics (STEM) research, and research-based education in the next ten years (World Bank & Elsevier, 2014). It is therefore important for researchers to continue evaluating the contribution of ESD towards 're-visioning' curriculum and pedagogy in science and technology education settings, as well as the quality and relevance of educational practices for all.

Conceptual Framework

The realisation of the vision to reorientate and enhance the quality and relevance of African education systems, for purposes of spearheading the sustainable use of natural resources, requires an understanding of the concepts associated with these aspirations. In this regard, we used the lenses of ESD and 'learning as connection' to analyse and reflect on the quality and relevance of learning achieved in the case studies presented.

ESD seeks to promote the quality of education that provides knowledge, skills and values for sustainability, and reorienting the curricula and pedagogy (UNESCO, 2014). Competences in sustainability relate to acquired knowledge, skills and attitudes that help in successful problem-solving with respect to real-world problems, challenges, and opportunities (Ulisses *et al.*, 2015). Solving these complex problems will require that students understand what connections exist across disciplines, as well as how to make those connections when looking at societal problems and working with communities on matters such as climate change and environmental degradation. Such issues are not solvable by application of scientific knowledge alone. As such, the notion of 'learning as connection' has evolved as part of the debate centred on inclusion of knowledge forms and practices found in many local communities that are typically excluded when educational quality and relevance are seen through the lens of mastery and efficiency alone (Lupele & Lotz-Sisitka, 2012).

A 'learning as connection' discourse of educational quality views learning as actively interfacing context and concept and thus making connections to socio-cultural, socio-ecological, personal, and communal life-worlds and experiences possible (Lotz-Sisitka, 2008). Learning as connection advocates for education to be connected to contextual and historical dynamics of learners' life-worlds and experiences, while simultaneously gaining mastery of concepts and content. It thus provides for contextualised and locally referenced approaches to quality in science and technology education, as argued by Shumba (2012). In the case studies presented in this paper, student researchers conducted authentic and relevant research in which they studied and used the research data to leverage local action and strategies to tackle issues such as carbon emissions and climate change. This is desirable learning for the 21st century, as clearly pointed out in the Southern Africa Universities Association (SARUA) (2014) report 'Climate change counts'.

Purpose of Analytic Paper

This paper analyses and reflects on the experiences in which a research team and student researchers are engaged in research projects investigating real life issues. In doing so, the paper seeks to suggest modalities for transforming curriculum and pedagogy in the area of science and technology education. The paper pursued the following questions:

- How can curriculum and pedagogy in a science and technology education setting be 're-visioned' for educational quality and relevance?
- How do ESD learning processes contribute towards a theory of 'learning as connection'?

Relevance to the Context

The Africa Union has a vision for Africa's sustainable development to be driven by science and technology. The vision aims to reorientate education with an ESD lens, as framed in the international discourse on educational quality. The following international processes on ESD suffice as examples endorsed by UN member states within Africa:

- The United Nations Decade of Education for Sustainable Development (UNDESD, 2005–2014);
- The Global Action Programme (GAP) for ESD from 2015 (UNESCO, 2014);
- The Incheon Declaration Education 2030 themed 'Towards inclusive and equitable quality education and lifelong learning for all' (World Education Forum, May 2015); and
- The United Nations Agenda 2030, themed 'Transforming our world' that contains the 17 Sustainable Development Goals (SDGs) (United Nations, September 2015).

SDG 4 target 7 in Agenda 2030 affirms the connection between ESD and educational quality, stating that all learners must 'acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles' (United Nations, 2015). Zambia endorses the above frameworks; hence, the latest *Zambia Curriculum Framework* seeks to integrate cross-cutting issues and ESD, and stresses the need to 'meet the individual and societal needs through learning' (Curriculum Development Centre, 2012:17). This reorientation of the curriculum requires innovations that must be shared widely. As it stands, there is not enough evidence available (even if anecdotally) as to how ESD contributes to the quality and relevance of science and technology education. This paper bridges this by providing and analysing case studies of student-teachers' ESD-oriented research projects within the science education department of a university.

Setting of the Case Study Projects

This paper analyses and reflects on researchers' experiences of and reflections on research projects they worked on with student researchers at the Copperbelt University in Zambia. The research team comprises a mix of natural scientists, science educators and an environmental management specialist. They considered the university to be an important site for ESD learning but did not fully understand its systematic integration into curriculum and pedagogy. As with academics elsewhere, they were preoccupied with their scientific disciplines. They tended not to preoccupy themselves with the curriculum and pedagogical issues considered relevant to the educational sciences. While in this setting mathematics and science student-teachers were favourably disposed to mainstreaming of ESD into courses, ESD issues were not formally taken into account in designing their courses (Shumba & Kampamba, 2012/13). In other contexts, integration of ESD issues is resisted for the fear of dilution of or distracting students from the mastery of 'scientific' technical content.

In the university, there is considerable flexibility when it comes to research project courses where a student and supervisor can exercise their creativity in identifying research problems and research designs for their investigation and solution. The pedagogical landscape permits co-supervision; thus, teams of scientists, environmental managers/engineers, and science educators can work together for interdisciplinary support and reflections. The research projects have proven to be an important vehicle for introducing senior students to real-world research and thus important and effectual avenues for experiencing ESD learning, for both student and supervisor. This paper analyses and reflects on the case studies to evaluate (a) how curriculum and pedagogy in a science and technology education setting ought to be 're-visioned' for quality and relevance and (b) what ESD learning processes contribute towards the educational development of students and a theory of learning as connection.

The Case Study Projects

UNESCO stated that the vision of ESD is 'a world where everyone has the opportunity to benefit from quality education and learn the *values, behaviour and lifestyles* required for a sustainable future and for *positive societal transformation*' (2000:5, emphasis by authors). Emphasis has been added to underscore the fact that each case study research project was selected for its contributions to changing the learning landscape (to achieve transformation in personal, institutional and societal lifestyles). Nine research projects are analysed to understand the broader meaning and contribution they are likely making in research, curriculum and pedagogy in a science and technology education setting.

Tables 1 and 2 provide a synopsis of each of the nine projects selected. The basic import of the projects was to get the student researchers to appreciate the socio-scientific issues of carbon emissions, climate change and the contributions that young people (in this case university students) make towards carbon emissions in various ways.

The featured projects in Table 1 are those relating to students' consumptive behaviours and conservation practices regarding, for example, water (case study #1) and electricity (case study #2); transportation associated with student commuting (case study #3); and the use of air conditioners and refrigerators (case studies #4). The main consideration of the project was to ensure that student researchers investigated real-life socio-scientific issues, so that they acquired scientifically, socially and technologically informed findings regarding emissions and their association with global warming and climate change. Student researchers were expected to reflect on their personal behaviours and practices that contribute to carbon emissions. They were to locate and work with web-based resources (e.g., carbon calculators and software to quantify carbon emissions) and to propose viable strategies to mitigate them as part of their professional learning for environmental management.

The doctoral research (case study #5) investigated the risk to endocrine system disruption associated with organochlorine pesticides and phenolic compounds such as Bisphenol A and alkyl phenol ethoxylates in the environment and in fish, as well as the public's levels of awareness to the risks. Bisphenol A and alkyl phenol ethoxylates are widely used in industrial applications and consumer products such as plastics and laundry products. These substances are receiving worldwide attention as disruptors of the endocrine system in humans and wildlife. In addition to generating knowledge on endocrine system disruption, the research has educational value for bringing awareness to consumers and in environmental management.

Table 1. Case studies with scientific, technological and environmental focus

Title of case study	Focus of case study
Case study #1: Male students' behaviour and attitudes towards water consumption and conservation in relation to climate change.	Determined consumptive behaviours and volumes of water usage and wastage, leading to an estimate of the water carbon footprint.
Case study #2: Consumption of electricity in students' halls of residence and its contribution to the university's carbon emissions.	Investigated the types of electrical appliances used and their temporal patterns of use, and quantified the amount of electricity consumed and carbon emissions.
Case study #3: Estimating the carbon footprint associated with student-commuting at Copperbelt University.	Estimated the carbon emissions associated with student-commuting and recommended commuting management strategies.
Case study #4: Assessing the carbon footprint of refrigerants at the Copperbelt University.	Surveyed and quantified the carbon footprint associated with refrigeration and air-conditioning.
Case study #5: Potential risks of endocrine disruptors along the Kafue River.	Explored the risk to and the public and their awareness of the risk associated with endocrine system disruption by Bisphenol A and alkyl phenol ethoxylates in the environment and in fish.

Note: Case studies #1–4 are at the Bachelor of Science (Environmental Engineering) level and case study #5 is at Doctoral level (Biological Sciences).

While the projects in Table 1 are principally focused on knowledge production and problem-solving in the context of studying a socio-scientific issue, the projects in Table 2 were implemented by Masters' level science educators. They demonstrate the recontextualisation of knowledge for science and technology education in a teacher education setting. Their point of departure, like the projects in Table 2, is a focus on working with student researchers to explore real-life and problematic socio-scientific issues while tackling the concepts in the curriculum. Case studies #6–7 in Table 2 demonstrate the impacts on learning when engaging science and technology students in real life biotechnology research involving characterising and culturing cyanobacteria in bio-fertiliser trial experiments (case study #6) and characterising Fe- and S-reducing acidophilic bacteria in a mined area (case study #7). The teacher-as-researcher in case study #7 developed and tested the efficacy of delivering subject matter via multimedia presentations (*PowerPoint* slides coupled with video animation).

The remaining case studies in Table 2 demonstrate initiatives to integrate climate change education into a science teacher preparation curriculum (case study #8) and teaching a science subject in a contextualised real-world context (case study #9). In the course of doing the projects, teachers-as-researchers came up with pedagogical strategies to assure that their students acquired relevant scientific and technological knowledge, knowledge of socio-scientific issues, and relevant environmental and ESD learning and skills.

Table 2. Case studies where scientific, technological and environmental is re-contextualised

Title of case study	Focus of case study
Case study # 6: Impact of engaging 4th year biology teacher education students in biotechnology research.	Explored the impact of engaging biology teacher education students in biotechnology research of cyanobacteria as biofertiliser.
Case study #7: Impact of using animations to teach DNA extraction to undergraduate students using an uncharacterised environmental sample from an actively mined area.	Evaluated impact of video animations in studying extraction and DNA characterisation of Fe- and S-reducing acidophilic bacteria.
Case study #8: Level of awareness of climate change concepts and the potential for greening the chemistry curriculum at Mufulira College of Education.	Engages lecturers and student-teachers in understanding and contributing towards designing the 'Green Chemistry Curriculum' at a college of education.
Case study #9: Impact of the Biological Science Curriculum Study 5Es Model on Zambian grade 11 learners' comprehension and attitudes on acid-base concepts in Chemistry 5070 studied in real world contexts.	Experimented with the Biological Science Curriculum Study 5E model and grade 11 students doing practical work with samples and materials in local environment.

Note: Case studies #6–9 are at the Master of Science (Science Education) level.

Analysis of the Projects

The nine projects were analysed by the research team using an analytic protocol developed for this purpose. An extract of the analytic criteria in the protocol are in Box 1. This protocol helped the researchers to qualitatively analyse and interpret educational and experiential knowledge accrued in the projects in a structured way, as recommended by Stake (2008).

Box 1. Criteria for evaluating scientific, educational, and societal impacts of the case studies

What value is added by the case study?
- Value added to our scientific and technological understanding.
- Value added to our understanding of the relationship between economic, environmental and social issues.
- Value added to decision-making capabilities of research team members.
- Value added to the quality of educational experiences.

What potential is there to transform some aspect of our curriculum practices?
- Potential to integrate of the subject matter content into research in the curriculum.
- Potential to connect learning of scientific and technological content to real life contexts, including social contexts.

- Potential to question people's actions and behaviours in light of the issues and findings.
- Potential to improve the relevance of the curriculum.

Are there any innovations or practical ideas coming out of the research project?

- Does it provide a viable solution to the problem?
- Does it have benefits to personal, community, and society?
- Does it provide unique ways of engaging students?
- Does it open scientific and technology knowledge to the wider community?

In the science and technology education and training of the university, what are the implications as you see them?

- A pedagogical approach to integrating development issues (e.g. environmental, social and economic issues).
- Connected learning in various disciplines.
- Promotion of multidisciplinary work and learning.
- Contextualisation of the curriculum.
- Integration of climate change and biodiversity.

The reflections of the team were focused on the 'big picture' pertaining to the overall meaning developed in the course of their execution. This big picture was assessed with ESD lenses and the learning as connection principle. An important question that was asked of each member of the research team was: 'What are the conceptual knots tying the project together?' This required each researcher to be reflective and to crystallise in their minds the wider meaning of the ESD research project in relation to the self, to science and technology, and in relation to appreciating the learning processes among student researchers as shown in the criteria in Box 1. In addition to the scientific and technological implications of research results, it was important to prospect for the educational and social implications of the research results.

Results and Discussion

The projects analysed are illustrative of ESD processes and learning. The projects engaged student researchers and supervisors in dealing with complex socio-scientific issues and development problems. Student researchers are learning to recognise ESD problems in the local institution and thus plan and implement investigations in which they collect data and use them as bases for action or proposing strategies to resolve the problem. A co-author of this paper reflected as follows on one of the projects:

> Electricity consumption in the university using students' residence halls is where the students embark on obtaining data and analyses it, provides real time data that fosters solving of problems within the community of practice while learning … The theory on carbon foot print calculations is brought closer to the students understanding by engaging in the research where analytical skills on climate change do not end with the figures but perceptions changing. (Choobe, co-author of this paper)

The case studies followed the pedagogical model of project-based learning (PBL) in which they confront and tackle real-life ESD issues (Segalàs, Ferrer-Balas & Mulder, 2010). As Segalàs, *et al.*

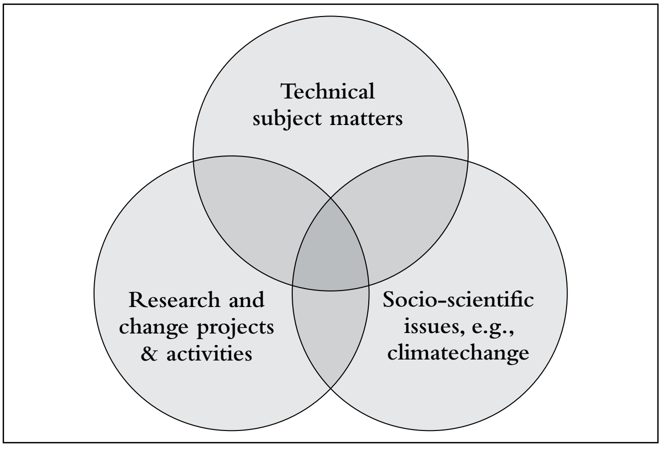
noted, this model provides an opportunity for student researchers to confront real-world issues and prepare them for solving challenges in society after university life. The PBL experiences had the following benefits:

- The projects improved student researchers' scientific and technological understanding of the issues and simultaneously raised their environmental awareness. One supervisor pointed out: 'As a supervisor, I was also able to observe how the student was able to intertwine the concept of carbon-offsets as a clean development mechanism and adapt it to his research.'
- The researchers viewed the projects as providing unique educational experiences for their students with respect to their ability to draw and use knowledge from several disciplines to solve a topical problem. For example, it was noted: 'In this study the student identifies a problem that affects the economy of the institution (electricity consumption) and links it to environmental problems of carbon emissions. The acquiring of the knowledge as being interconnected develops in the student.'
- Researchers reflected that engaging student researchers in projects of this nature had the potential to transform aspects of local curriculum practices in two ways:
  - Integrating research and the subject matter content of the research in the curriculum; and
  - Connecting scientific and technological content to real life contexts (including social contexts), thus improving the relevance of the curriculum.
- There were potential innovations and/or practical ideas that came out of the research projects; e.g., designing change projects, cost-saving measures, integrating socio-scientific issues in teaching and learning, and creating ICT and multimedia-based lessons.

In some of the case study projects, the student researchers tackled issues pertaining to climate change and its impacts. In others, they studied micro-organisms and tested their efficacy as bio-fertilisers. In science and technology education projects, they had to be innovative in order to effectively recontexualise scientific and technological knowledge into forms to be learned by non-professional scientists. To accomplish these tasks, student researchers were required to have acquired knowledge from several disciplines. In all projects analysed, student researchers required deep scientific and conceptual knowledge in chemistry, physics, biology, mathematics and engineering in order for them to provide efficient and sustainable solutions to contemporary global and local societal challenges. However, current university science, engineering curricula, and educational sciences do not provide such interdisciplinary courses and programmes.

It would appear that engaging them in projects that focus on socio-scientific issues ensures that the projects are interdisciplinary. This has benefits, as student researchers began to see their projects as enabling them to explore the interfaces between natural sciences and social sciences, and to make a link between scientific and humanistic dimensions of learning. The need to gain scientific knowledge of, for example, climate change science, should not be the be all and end all of learning in science education. Learning must include an understanding of the development issues associated with climate change and an appreciation of practical ways to act and do things to cope with or mitigate its impacts (see, for example, Eilks, 2015). The analysis here shows that the projects provided opportunities to engage with scientific and technological subjects while also engaging with socio-scientific issues, and to propose or test change projects. Figure 1 suggests that pedagogical and curriculum innovations are needed to assure balanced treatment of subject matter contents, socio-scientific issues, and research or change projects/ activities to apply this knowledge to deal with developmental issues.

Figure 1. Balanced treatment of subject matter contents, socio-scientific issues, and research and change projects/activities



Source: Shumba *et al.*, 2012/2013

Implications: 'Re-visioning' Curriculum and Pedagogy and Learning as Connection

The experiences outlined above have shown that project-based learning focussed on socio-scientific issues can provide a context for problem-solving, knowledge generation and its recontextualisation, and for innovation in pedagogy in STEM education. The ESD processes that they entailed also have implications for 're-visioning' quality and relevance in STEM education. It has been shown that the creative nature of research projects makes it less rigid to investigate socio-scientific issues and create spaces for ESD learning. Properly conceived research projects guiding student researchers to draw knowledge from several disciplines can serve to break down the disciplinary cocoons in tertiary education, a major desirable shift for curriculum and pedagogy. Another important guiding point is in ensuring that they propose or design strategies to resolve the issues they find. For example, they ought to suggest carbon emissions management plans that involve them and other stakeholders, or pedagogical strategies to bring the process and results of real world science and technology investigations into classrooms. Furthermore, guidance ought to be provided on how to engage stakeholders with their sustainability action plans to mitigate a lack of knowledge or poor attitudes towards dealing with sustainable development issues. For example, in the various case studies, the survey components revealed poor knowledge concerning climate change and issues associated with it among university students.

The collaboration among the different specialists supervising the research projects also brings attention to what can happen to knowledge produced in the science departments if made available to science educators in teacher education. Here, it may be important to reflect on a point or two from sociologist Basil Bernstein. Bernstein's principle of recontextualisation is a pedagogic discourse, an ensemble of rules or procedures for the production and circulation of knowledge within pedagogic interactions (Singh, 1997) between science departments (that are fields of knowledge production) and science education departments (that are fields of reproduction, circulating the scientific knowledge). Recontextualisation, it would appear, is facilitated by collegiality and interdisciplinary collaborations among scientists, and science educators (and their students). In this case, knowledge and innovations in the research projects may be brought into the science curriculum for teachers and for schools. Pedagogical transformation is possible where socio-scientific issues are effectively integrated, balancing the science and technology content with consideration of the problematic development issues.

Besides the implications above, the experiences in these case studies are united by several 'knots' reflected in the concepts and practices that the researchers identified with: socio-scientific issues, cross-cutting issues, transfer of learning, interdisciplinary and multidisciplinary research, integration contextualising, community of practice, and several others. All of these concepts and practices point to connections and inter-connections that provide an important context for 're-visioning' of curriculum and pedagogy in the manner asserted above. This provides a case for learning as connection as a useful notion for understanding quality and relevance.

Conclusion

The challenge in ensuring educational quality and relevance, especially in Africa, is how to make the curriculum and educational experiences transformative for the individual and their society. Integrating and investigating real world socio-scientific issues in the curriculum and pedagogy can be achieved by utilising a project-based learning approach. As seen in the case studies, project-based learning with an ESD orientation provides the learners with real-life problems and a context for learning as connection.

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Notes on the Contributors

Professor Overson Shumba has research interests in ESD, chemical education and science teacher education. He is a former Fellow of the W.K. Kellogg Foundation and the German Academic Exchange Services, and member, UNESCO Monitoring and Evaluation Expert Group on the DESD 2005-2014. Email: oshumba@yahoo.co.uk

Dr George Kasali is an environmental microbiologist and senior lecturer with research interests in microbiology, climate change, bioenergy and environmental pollution.

Ms Beauty Choobe holds an MSc in Biology Education and has research interests in biology and ethnobiology education pedagogies.

Dr Moola Mutondo is a plant geneticist with a PhD from Max Planck Institute for Plant Breeding Research in Cologne. Her interest is research on organisms existing in extreme conditions.

Ms Gezile Mbewe-Chalwe is a molecular biologist and a doctoral candidate in biotechnology. Her research interests are in ecotoxicology, natural product chemistry, environmental biotechnology and food nutrition.

Professor Kakoma K. Maseka is a chemist with interests in chemical education, natural dyes and environmental chemistry with focus on polychlorinated aromatics and remediation of sites polluted with heavy metals.

Ms Yaki Namiluko is a lecturer in the Department of Environmental Engineering. She has research interests in natural resources management, climate change, remote sensing and geographical information systems.

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