TERTIARY EDUCATION AND CAPACITY DEVELOPMENT IN BIOTECHNOLOGY IN THE SOUTHERN AFRICAN DEVELOPMENT COMMUNITY (SADC)

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A thesis submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

Johannesburg, 2013

Declaration

I declare that this thesis is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

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8th day of **May 2013** in **Johannesburg**

Abstract

Biotechnology as a science has become increasingly more important because of what it has to offer in various fields. These include the development of medicines for human and animal health; improved crop agriculture for enhancing food security; and environmental sustainability, all of which are of the utmost importance, not only globally, but also in southern Africa. Through a participatory and collaborative process of biotechnology capacity development at the Universities of Namibia (UNAM) and the Witwatersrand (WITS) in the Southern African Development Community (SADC) region, it was identified that science curricula need to take cognizance of 'worldview' and the impact this may have in the context of teaching and learning. The purpose of this study was to investigate the potential barriers, or factors contributing, to learning in the two southern African universities in the context of the biotechnology curriculum. The study focused on how African epistemologies should be taken into consideration to facilitate capacity development in biotechnology at the tertiary education level, and in so doing, facilitate the development of a culturally sensitive, generic biotechnology curriculum which reaches across both literal and cultural borders and is relevant to these countries. The methodology of phenomenography was used in this case study and it resulted in two categories of description that formed the outcome space of the experience of biotechnology. These categories of description included a theoretical and practical perspective and a worldview perspective. This study has confirmed that worldview differences can lead to barriers to learning in biotechnology. Furthermore, theoretical and practical concepts included in the curriculum need to be carefully considered to make the curriculum responsive to African needs in order to provide for epistemological access, and so that the inherent cross-cultural experience between the learners' life-world and biotechnology is recognized. The value of this study is affirmation that formulation, development, teaching and learning of a biotechnology curriculum should be regarded as an 'African product', where worldview and the theoretical and practical perspectives are carefully considered to provide a qualification to make a difference for capacity development in southern Africa. (339 words)

Dedication

I dedicate this work to my family:

My husband, **Greg**

Our two children, **Hamish** and **Caylee**

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I thank SANTED (2006-2010), Carnegie Grant (2011-2012) and University of Witwatersrand Ad Hoc Teaching and Learning Grant (2008) for the financial support at different times to do this research.

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Publications associated with this study

All the papers listed below were double-blind peer reviewed.

1. **Mollett J.** and Rey C. **2008** Biotechnology capacity development in southern Africa: Aspirations, Inspirations, and Perspirations. XIII. IOSTE Symposium, The use of Science and Technology Education for Peace and Sustainable Development. 21-26 September 2008, Kuşadasi, Turkey. ISBN 978-605-5829-16-2

2. **Mollett J.,** Rey C. and Cameron A. **2010** Sociocultural and Human Values in Biotechnology Tertiary Education in southern Africa. XIV IOSTE 2010 Symposium, Socio-cultural and Human values in Science and Technology Education. Proceedings. 13-18 June 2010, Bled, Slovenia. Editors: Borut Lazar & Robert Reinhardt. ISBN 978-961-92882-1-4

3. **Mollett J.M.,** Cameron A. & Rey M.E.C. **2011** Crossing Borders in Biotechnology tertiary education in southern Africa. The International Journal of Learning 18(5): 37-48. ISSN: 1447-9494 © 2011

These three publications frame the essence of the study and they highlight different years of the work and how it all grew to the final thesis. They have provided the platform on which my thoughts, confidence and interest have evolved.

Publication 1 concerns the origins and background of the project. It is all about the South African and Norwegian Tertiary Education Development Programme (SANTED) and working with the development of the biotechnology curriculum in the southern African Universities.

Publication 2 is a case study on the results of development and progress in relation to the biotechnology curriculum development at the University of Namibia (UNAM) (2009-2010 cohorts).

Publication 3 covers the methodology and the beginning of the data analysis.

Papers presented at International conferences

Mollett J. and Rey C. **2008** Biotechnology capacity development in southern Africa: Aspirations, Inspirations, and Perspirations. XIII. IOSTE Symposium, The use of Science and Technology Education for Peace and Sustainable Development. 21-26 September 2008, Kuşadasi, Turkey. ISBN 978-605-5829-16-2

Mollett J., Rey C. and Cameron, A. **2010** Sociocultural and Human Values in Biotechnology tertiary Education in Southern Africa. XIV IOSTE 2010 Symposium, Socio-cultural and Human values in Science and Technology Education. Proceedings. 13-18 June 2010, Bled, Slovenia. Editors: Borut Lazar & Robert Reinhardt. ISBN 978-961-92882-1-4

Mollett J. **2011** Crossing Borders in Biotechnology Tertiary Education in southern Africa. The 18th International Conference on Learning. University of Mauritius, 5-8 July 2011.

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List of Acronyms

APB	Agricultural and plant biotechnology
AAU	The Association of African Universities
CHE	Council on Higher Education
CSIR	Council for Scientific and Industrial Research
DART	The Directorate of Agriculture and Training
DNA	Deoxyribonucleic acid
DST	Department of Science and Technology
FAO	Food and Agriculture Organization of the United Nations
GE	genetic engineering/ genetically engineered
GM	genetically modification / genetically modified
GMO	genetically modified organism
HGP	Human Genome Project
HOGRAN	Hoodia Growers' Association of Namibia
ICRISAT	International crops Research Institute for the semi-Arid Tropics Regional Programmes on Sorghum and Millets Improvement
IK	indigenous knowledge
IKS	Indigenous knowledge system
IP	Intellectual property
NABA	Namibian Biotechnology Alliance
NRF	National Research Foundation
OECD	The Organization for Economic Co-operation and Development
PCR	Polymerase chain reaction
PGE	Plant genetic engineering
PB	Plant breeding
QA	Quality assurance
SADC	South African Development Community
SANTED	South African and Norwegian Tertiary Education Development Programme
STS	Science-Technology-Society education
T&L	teaching and learning
TEK	traditional ecological knowledge

TIA	Technology Innovation Agency
UEM	University of Eduardo Mondlane
UIS	United Nations Educational, Scientific and Cultural Organization Institute of Statistics
UN	United Nations
UNAM	University of Namibia
UNESCO	United Nations Educational, Scientific and Cultural Organization
USA	United States of America
UWC	University of the Western Cape
WHO	World Health Organization
WITS	University of the Witwatersrand
WMS	Western modern science

Tertiary Education and Capacity Development in Biotechnology in the Southern African Development Community (SADC)

Chapter 1 – Rationale and motivation for this research study

1.1. Introduction

Biotechnology as a science has become increasingly important globally because of what it has to offer in various fields. These include the development of medicines and the improvement of techniques for human and animal health, and for enhancing food security in crop agriculture. Biotechnology had its beginnings in the neolithic revolution 10,000 years ago with the emergence of agriculture, and since then there has been constant development of new products and techniques. The "biotech revolution" of the 1970's (Zwart, 2009) firmly established Biotechnology as a discipline. However, the concept "biotechnology" has many ambiguities, especially when it is connected with the terms "genetic modification" and "genetically modified organisms" (GMOs). The textbook definition of biotechnology is "any technological application that uses biological systems, living organisms or derivatives thereof, to make or modify products or processes for specific use" (http://www.epa.gov/OCEPAterms/). Modern biotechnology involves manipulating DNA. This manipulation of DNA, or genetic engineering, refers to the use of genetically modified (GM) organisms in agriculture and industry (Campbell and Reece, 2005). Universities, research institutions and industry work towards the development and application of biotechnology where areas of interest such as crop agriculture, animal and human health, and environmental sustainability are of the utmost importance (FAO, 2010), not only globally, but also in southern Africa. However, it is emerging that there is a lack of biotechnology capacity among scientists in the Southern African Development Community (SADC), in both the theory and applications of biotechnology (Mthembu, 2006). Consequently it is vital that the skills required for establishing biotechnology knowledge should be promoted through capacity training at secondary and tertiary institutions in the SADC region.

1.1.1. The demand for capacity development

According to the Organization for Economic Co-operation and Development (OECD, 2007), capacity development refers to the process whereby organizations and societies adapt and maintain capacity in different fields over time. Capacity development therefore depends on progressive involvement in these fields and in the achievement of high skills by those working in them. Tertiary education contributes to capacity development by training the country's human resources in fields relevant to its development (OECD, 2007).

The demand for capacity development therefore presents new challenges and huge opportunities for those involved in tertiary education, and in most countries the demand for tertiary education is increasing. This growth is related to factors such as changing demographics; a greater number of secondary school graduates; the movement to lifelong learning; and the growth of knowledge-based economies (Knight, 2007). Because of this rapid growth and the rapid growth in knowledge, alternative ways are being developed to satisfy the demand for tertiary education. Knight (2007) has pointed out that the alternative ways to satisfy this demand include, for example, growth in the private education sector; a greater emphasis on distance education due to advancement in information and communication technologies; and new developments in cross-border education. The Global Student Mobility 2025 Report by Bohm *et al.,* in 2002 (as cited by Knight, 2007) predicts that the demand for international education will increase from 1.8 million international students in 2000 to 7.2 million international students in 2025. According to the United Nations Educational, Scientific and Cultural Organization (UNESCO) Institute of Statistics (UIS) data, there were at least 3.6 million students enrolled in tertiary education in foreign countries in 2010. These students are called "internationally mobile students", which refers to students who cross national borders to study or enrol in distance learning programmes. In 2010, South Africa was amongst the top three destinations for these "mobile" students from sub-Saharan Africa: France received 19%, South Africa received 17% and the United Kingdom received 12% of these students (http://www.uis.unesco.org/EDUCATION/Pages/international-student-flow-viz.aspx). Together with the increasing rate of student movement, there is also an increase in the number of education providers from various institutions who now move across national borders to deliver courses to students (OECD, 2004). In southern Africa, the provision of such courses falls within the objectives of the SADC protocol on education, one of which is to maximize the effective utilization of existing expertise to ensure long term sustainability. This increase in the demand for tertiary education, together with the increasing mobility of students, highlights the need and demand for capacity development in Higher Education. This is especially true in developing countries, where a contextually relevant curriculum could facilitate capacity development.

1.1.2. Biotechnology as an emerging field for capacity development in southern Africa

The field of biotechnology has become important because of technological developments and the scientific consequences thereof. The scientific applications of biotechnology include many different scientific areas and skills, including biochemistry, genetics, microbiology, information technology and engineering. At the University of the Witwatersrand (WITS) biotechnology has become one of the important research areas in the Faculty of Science. This follows a global trend in scientific research. In line with this, the University of Namibia (UNAM) introduced new biotechnology courses into their curriculum in 2009, and a project was set up in 2006 between WITS and UNAM to help build and strengthen existing biotechnology capacity at WITS, as well as develop biotechnology capacity at UNAM. This was to be achieved through regional co-operation through cross-border teaching and collaboration (Mthembu, 2006). The project had its beginnings in a larger project called the South African-Norway Tertiary Education Development Programme (SANTED), the major objective of which was to enhance co-operation and build partnerships between UNAM, WITS and Universitas Eduardo Mondlane (UEM) in Mozambique. One of the objectives of this project was capacity development in both the theory and applications of biotechnology through the introduction of relevant curricula and the strengthening of existing curricula. SANTED was a Norwegian-funded, government-to-government development project which ended in August 2009, with the 'close-out' conference being held in September 2010. The outcomes of this project included, firstly, the introduction of biotechnology courses at UNAM, which were approved by the UNAM Senate at the end of 2007. These modules continue to be offered in the 3rd and 4th years of the undergraduate degree and were taught for the first time in 2009 and 2010 at UNAM. UEM did not get as far as introducing the courses because of language issues: all materials needed to be translated to and from Portuguese and there was not capacity for this. Other problems included the UEM institutional culture and a general unresponsiveness to the program which resulted in them dropping out.

The second outcome of the SANTED project was the growth of interest in regional cooperation through cross-border teaching and collaboration. The focus of this collaboration between WITS and UNAM was to develop the skills, theory and application of biotechnology. In addition to capacity development at UNAM, this outcome fitted in with the WITS 2020 strategic plan of developing its reputation as a 'research driven university' and of 'developing strategic partnerships that will make it an active, committed, creative, innovative force that advances the public good'
(WITS Mission and Vision Document:
http://www.wits.ac.za/aboutwits/introducingwits/missionandvision/3160/missiona33ndvision.html).

A further outcome of the SANTED project, and the one that forms the basis for this study, is the recognition of the need to acknowledge the potential of worldview differences in the development of a culturally sensitive and contextually relevant curriculum. South Africa and Namibia are countries which have recently emerged as democracies, keen to develop their own identities and provide education systems which reflect a multicultural heritage concomitant with global driving forces that shape social, political and economic growth.

1.2. The research problem

The literature in science education shows that culture has an impact on learning. This means that ontological and epistemological differences related to worldview can have serious implications for the learner. Jegede argues that prior knowledge (with its cultural basis) could affect African students in their learning of western science (Jegede 1997, 1998). The concern arises in terms of science being taught in places where epistemologies are context-specific. To assist learning, authors including Jegede (1998), Aikenhead (1996), and Ogunniyi (1988, 2002) have advised that it is necessary in multicultural contexts to recognize the differences and difficulties experienced by students in learning science because of worldview concern.

Southern African society is enormously diverse in terms of its culture. The education system is still based on the legacy of colonial influences, and there is a continuing pressure for global relevance and standards. The biotechnology courses offered at WITS and UNAM are based on a western science epistemology and western science content. During the collaboration process between WITS and UNAM it became apparent that worldview differences existed in terms of a western curriculum being offered in an African context.

Ideas regarding biotechnology have evolved in various socio-historical contexts. Their historical origins determine their actual meaning and use in contemporary deliberations. The practice of technology is defined as the practical application of knowledge (Merriam-Webster Dictionary, 2003) and has been practiced by humans for survival since prehistoric times (Stahl, 1986). This application of knowledge for survival is the basis of all technology, including the technology of indigenous African communities. Colonization and globalization have “telescoped” scientific and biotechnological ideas and products and imposed these on third world countries where indigenous worldviews are still prevalent. These indigenous worldviews with their associated indigenous knowledge systems (IKS) are now being recognized as needing protection. In support of this, Odora-Hoppers (2002, p53) pointed out that there is a “postmodern integrative paradigm shift” where there is scope for complementarity between indigenous and western knowledge systems. This paradigm shift addresses a “second generation indigenization” where the errors of the past are becoming starting points for new directions which include recognizing indigenous knowledge (IK) (Ibid., 2010, p15). In fact there is even recognition that these indigenous knowledge systems are needed (Odora-Hoppers, 2010), for example in relation to the development of new pharmaceutics. This recognition of considering and protecting indigenous knowledge is emphasized by Jegede (1997, p17) who said: “Instilling scientific culture in a people, who learn western science with a traditional worldview, must of necessity begin from their cultural attitudes towards, and local knowledge about, their environment”. Cobern (1993) has argued that there can be issues of learning in cross cultural contexts, where the cultures he was referring to included relating to the students' culture, the teachers' culture and the culture of science.

This understanding, that there are differences in worldview that are important in the teaching and learning (T&L) of science provided the basis for this research study. The existence of differences in worldview i.e. western vs. African ways of knowing has been shown to lead to epistemological barriers, which affect learning and the transfer and application of knowledge. Consequently, the development of an appropriate curriculum for biotechnology capacity development is needed to take this into account. Doughty (2005, p6) has stated that "(w)estern conquest effectively dispossessed indigenous epistemologies" i.e. that western scientific curricula have been imposed on African countries in a very arrogant way. Biotechnology is a new, exciting and growing field, and a different "culture" within science. This underlines the need for the development of a biotechnology curriculum which provides for different epistemologies.

Research has established that epistemological barriers play a significant role in effective teaching and learning (Stanley & Brickhouse, 2000; Cobern, 1996). In the context of southern Africa, Morrow (2009, p77) coined the term "epistemological access" to describe the barriers to successful learning that are linked to worldview differences. Epistemological access requires an understanding about epistemic values which are values that shape and guide inquiry (ibid.). Morrow further argues the need to do away with the Eurocentric curriculum and the need to acknowledge that Africa has its own "alternative forms of knowledge" (p34). Recognizing that teaching and learning in the SADC region takes place in multicultural classrooms, concern therefore arose regarding potential barriers to learning in biotechnology.

Having been alerted to the potential impact of worldview on the teaching and learning of science through the literature, the purpose of this research study was to investigate the existence of African worldviews and epistemologies in the field of biotechnology in order to inform teaching for capacity development in this region. This may be regarded as ground breaking research as it is new in the field of biotechnology teaching and learning, and has not been undertaken before in southern Africa. The purpose is further to inform the development of a culturally sensitive and contextually relevant biotechnology curriculum which can then be offered as an 'African' product, rather than the more typical practice of imposing a Eurocentric curriculum which has not been adapted to the local environment. This study was carried out in line with the objectives of the SADC countries, which include long-term, sustainable solutions to problems in areas such as health and food security and the economic enhancement of the region.

1.3. Objectives of this research

The objective of this research study was thus to investigate whether worldview differences concerning biotechnology exist, and if they do, whether they contribute to epistemological barriers in teaching and learning in the two SADC institutions involved i.e. University of the Witwatersrand (WITS) and University of Namibia (UNAM).

1.4. Research questions

In order to facilitate this investigation, the following research questions were posed in the context of WITS and UNAM biotechnology courses.

Research question 1

What worldview concerns might be associated with the biotechnology curriculum?

Research question 2

How do these worldview concerns affect "epistemological access" in terms of the biotechnology curriculum?

Research question 3

How can the outcomes from questions 1 and 2 inform the biotechnology curriculum?

The three research questions were used as the basis for establishing the existence of any beliefs or views that could potentially impact engagement with the ideas of biotechnology and thus affect student understanding of the concepts involved in biotechnology. The findings would then provide the opportunity to meaningfully contribute to a transformed i.e. culturally sensitive biotechnology curriculum that accommodates learning in the context of worldview differences, thus meeting the need for the provision of epistemological access in multicultural institutions such as UNAM and WITS.

1.5. The theoretical framework for the study

Having recognized the need to address the question of epistemological access, the theoretical framework on which the study is based is the concept of worldview and its impact on learning. Cobern (1996) argues that worldview "provides a person with presuppositions about what the world is really like and what constitutes valid and important knowledge about the world". While a scientific worldview holds that knowledge is gained through prediction and experiment producing knowledge that is universally true, the African worldview is that knowledge is a gift from the ancestors: it is a social and tribal entity, and therefore while it may not be universal (Hamminga, 2009) it does form the basis for belief about the world and how it works. African epistemology is characterised by strong interpersonal relationships, peace with nature, communalism and spirituality. This epistemology places emphasis on ethics and morality, symbolic imagery, self-awareness and tradition (Bakari, 1997). Snively and Corsiglia (2000) used the term indigenous knowledge (IK) to refer to the knowledge acquired over thousands of years of human contact with the environment. IK is generally passed on verbally through generations where it is more about preserving existing knowledge and wisdom from the past, rather than about generating new knowledge. It has been acknowledged that some IK can have 'science' in it (Van Eijck and Claxton, 2009) such as the scientific principles involved in the brewing of beer and milk and cheese fermentations. However, IK includes other forms of knowledge, e.g. traditional folklore and indigenous metaphysics (Cameron, 2007). All these forms of knowledge collectively contribute to the shaping of worldview.

The concept of worldview highlights the difficulties that may be linked to the transition that needs to be made between a student's life-world and science for learning to be successful (Aikenhead, 1996). Aikenhead described using science as a "cross-cultural experience". He coined the term "cultural border crossing" to refer to the process of having to move from one worldview state to another. According to Aikenhead and Jegede (1999, p274), "enculturation" may occur when science instruction is supported by a student's life-world culture and view of the world and the student is able to incorporate the ideas into their knowledge base. “Assimilation” is the process when science instruction disrupts the student’s view of the world by ‘trying to replace it or marginalize it’. Both the processes of enculturation and assimilation require cultural border crossing into the ‘subculture’[1] of science. However, Aikenhead and Jegede (1999) suggested that enculturation is more likely to occur in students whose life-world is closely aligned with science, because they can more easily “cross the border”. However, assimilation redirects student thinking leading to them reconstructing their ideas.

This brings about the question of whether it is possible to integrate knowledge from the two different worldviews especially when considering the “postmodern integrative paradigm shift” referred to by Odora-Hoppers (2002), where indigenous knowledge and western knowledge systems complement each other. Lewis and Aikenhead (2001) questioned the possibility of integration, claiming that integration would have the long term outcome where traditional knowledge would lose its identity and become subsumed by western modern science (WMS). However, Odora-Hoppers (2002, p53) recommends using IKS as a “counter-hegemonic tool” - in order for Africa’s problems to be solved by Africans: she claims the way to do this is to restore and revitalize indigenous knowledge, through the recognition of indigenous knowledge systems and the recognition that they are needed in the subcultures of science and society in southern Africa. Odora-Hoppers (2010) further argues that by embedding indigenous knowledge in science teaching and learning, the core values from different traditions of knowledge and life practices will become strengthened.

The purpose of scientific education is to develop people as “scientifically literate”. A person becomes “scientifically literate” in varying degrees depending on their background. Definitions of scientific literacy mostly include the acceptance and application of science in everyday life, but this is facilitated where people have a scientifically compatible worldview (Cobern, 1996). Where concepts do not fit in with students’ natural way of thinking, such concepts are

[1] Aikenhead (1997) calls the ideas , beliefs, views associated with subgroups, such as families, peers, media, and the school as constituting ‘subcultures’.

“compartmentalized” (Waldrip and Taylor, 1999). Cobern (1996, p588) refers to this compartmentalization as “cognitive apartheid”, where different forms of thinking are retrieved according to context. For students this may mean that ideas from science are only retrieved on certain occasions such as in an exam, but that they have not really shifted in their belief about the phenomenon. Cobern (1996, p584) further argues that worldview offers a “non-rational foundation for thought, emotion and behaviour”. This supports the idea that students could be anxious about learning science because they feel discomfort concerning science. The view of learning science as culture acquisition is a practical extension of constructivist theories and according to Aikenhead (1996) it allows for a perceptive and rich appreciation of students’ experiences in a science classroom. However, Cobern (1996) cautions that while there are fundamental cognitive differences among people, this does not mean that every cultural or social difference is the result of a different worldview (Cobern, 1996). Rather, what it means is that a worldview can elicit various different perceptions of a concept, depending for example on factors such as the environment in the science classroom.

The question is whether it is possible to integrate knowledge from the two different worldviews. Odora-Hoppers (2002) strongly argues for complementarity between indigenous and western knowledge systems, supporting the idea of the knowledge becoming more of an intellectual resource than just for exam use. Furthermore, the incorporation of indigenous knowledge in the science classroom could result in the inclusion of those who have been excluded, i.e. “epistemologically disenfranchised” (Odora-Hoppers, 2010, p16) because of western hegemonic science curricula. By integrating knowledge from the two different worldviews a “holistic knowledge framework for societal development” (Odora-Hoppers, 2002, p27) could then be provided.

Studies conducted in South Africa and other parts of the world have identified that worldview differences can lead to barriers to learning which can hamper cultural border crossing (Cameron, 2010; Prosser and Trigwell, 1999; Cobern, 1996). In the light of these studies this research study investigates the potential worldview barriers to learning in biotechnology. This could facilitate the development of a culturally sensitive, generic biotechnology curriculum which reaches across both literal and cultural borders and is relevant to these countries, to provided the "holistic knowledge framework for societal development" as suggested by Odora-Hoppers.

1.6. Conclusion to Chapter 1

In this qualitative research study the research questions posed required an in-depth study of the qualitatively different ways lecturers and students at WITS and UNAM experience, conceptualize and understand biotechnology, with the theory of worldview providing the theoretical framework. Phenomenography was seen as the most appropriate research methodology for this study, because of its flexibility in allowing for the emergence of the findings. Questionnaires, interviews and focus groups were used to gather data. The assumptions that were made are that (1) the participants responded honestly and thoughtfully to all questions in the questionnaires, focus groups and interviews and that (2) the participants were representative of the population of lecturers and learners involved in biotechnology teaching and learning at the two institutions. The findings would then provide the opportunity to meaningfully contribute to a transformed i.e. culturally sensitive biotechnology curriculum that accommodates learning in the context of worldview differences, thus meeting the need for the provision of epistemological access in multicultural institutions such as UNAM and WITS.

1.7. The structure of the thesis

With Chapter 1 having presented an introduction to the study, the second chapter contains a review of the literature that served to inform the study. The three main ideas presented in chapter 2 concern the nature of biotechnology, the nature of epistemology and the nature of tertiary education. The first section, ***the nature of biotechnology,*** addresses the development of biotechnology as a discipline; the status of biotechnology in southern Africa, (specifically South Africa and Namibia); biosafety concerns; and the legislations, policies and regulatory frameworks in place. The next section, ***the nature of epistemology***, looks at the epistemologies of science and technology, together with traditional ecological knowledge and African epistemology. As the recommendations of this research will inform biotechnology capacity development at the tertiary education level through curriculum development, the final section, ***the nature of science tertiary education,*** gives an overview of the effect of globalization on tertiary science education, then leads on to cross-border education, cultural border crossing and collateral learning and how an understanding of African epistemology could lead to the development of a culturally sensitive curriculum. The third chapter presents my positionality statement, which includes a description of my biography, perspectives and biases, to highlight how my background may have influenced my perceptions of and choices of the methodology and analysis of the study. This chapter then serves to also inform what may be regarded as the limitations of the study. The fourth chapter looks into the research methodology by beginning with a background on qualitative procedures and discussing the research methodology chosen for this research, i.e. phenomenography. It then goes onto the research design, instruments, data collection and analysis, and finally a discussion on the trustworthiness of the research. The fifth chapter presents the data analysis, results and interpretation of the findings. This is presented in the form of an outcome space. The final sixth chapter discusses the findings, makes recommendations, highlights the conclusions and summarizes the study.

Chapter 2 – Literature review

2.1. Introduction

The literature that was reviewed informs the research that was undertaken. The chapter begins by highlighting the importance of biotechnology as a discipline, including its many applications such as sustainable solutions to problems in areas like health and food security and economic enhancement. The concerns associated with biotechnology are also discussed. This is followed by the status of biotechnology in southern Africa, with sections specifically addressing South Africa and Namibia. The biotechnology practices that form the focus of this study are agricultural and plant biotechnology (APB). Because the study investigates worldview concerns that may affect "epistemological access" in relation to the biotechnology curriculum, and as it has been established that epistemological barriers play a significant role in effective teaching and learning (Stanley & Brickhouse, 2000; Cobern, 1996), the next section on the nature of epistemology, looks at differences in epistemology. This section thus includes discussion of the epistemology associated with science and that associated with technology (i.e. techno-epistemology) together with traditional ecological knowledge (TEK) and African epistemology. As the recommendations of this research will inform biotechnology capacity development at the tertiary education level, the final section, the nature of science tertiary education, gives an overview of science tertiary education and cross-border education, together with the effect globalization has had on both. With the effect of globalization a greater demand is placed on the use of science and technology as the basis for improving quality of life and tertiary education institutes provide the educational vehicle to achieve this. Finally, the theories of cultural border crossing and collateral learning are discussed. These two theories which emanate from worldview theory explain how students move between everyday life worlds and the world of science and how they deal with the conflicts between the two worlds. This literature review informs the study by laying the foundations for considering how an understanding of African epistemology can lead to a culturally sensitive and relevant biotechnology curriculum which reaches across both literal and cultural borders.

2.2. The nature of biotechnology

2.2.1. The discipline of biotechnology

Biotechnology encompasses techniques that use biological systems, living organisms or derivatives thereof to make or modify products or processes for specific use (UNEP, 1992). That biotechnology involves the manipulation of organisms to make products useful to humankind dates back many centuries. Studies of biotechnology (Ratledge and Kristiansen, 2001; Stewart and McLean, 2005; Fridman and Zamir, 2012) have indicated that there are three major phases with different product developments in each phase, where each phase is referred to as a 'generation' (Stewart and McLean, 2005). The 'first generation' involves the use of biological organisms to produce food and drink e.g. cheese and beer. The techniques used in this first generation of biotechnology are fermentation, and animal and plant breeding. The 'second generation' is the use of pure cell or tissue culture to yield new products, such as antibiotics and enzymes. According to Stewart and Mclean, this includes plant quality characteristics such as nutritional content. Plant tissue culture, a requirement for agricultural and plant biotechnology (APB) has many applications, such as disease eradication, rapid clonal multiplication, production of dihaploids from anthers or ovules (for breeding pure lines), regeneration of plants from organ culture, germplasm storage, and embryo rescues in interspecies hybrids (Trigiano and Gray, 2000). The 'third generation' involves the use of recombinant DNA technology, also a requirement for APB. This has many uses, from bioremediation to pharmaceuticals for human health care. According to Ireland and Hine (2007) the development and application of biotechnology includes all areas such as drug design, environmental remediation, protein engineering, biocontrol and plant genetic engineering. These many areas of biotechnology highlight the convergence of the skills associated with biochemistry, genetics, microbiology, information technology and engineering, genomics (which is the study of the genomes[2] of organisms), and proteomics, required in biotechnology.

[2] The etymological origin of the "ome" in genome is unknown, but according to Lederberg and McCray (2001) it has a phonological tie to the Sanskrit OM which describes the unlimitedness of divinity in the universe. This idea of

While increased genetics knowledge has for example helped plant breeders improve crops for enhanced yield and quality (Suslow *et al*., 2002), genomics has hugely increased the volume of information produced by biotechnology techniques (Allison *et al*., 2009), highlighting the 'tsunami' of information developed by biotechnology applications and skills.

Borbone (2009) has highlighted that there are criticisms and doubts around biotechnology. He uses three dogmas (or principles) to interrogate these criticisms. The first of these, the dogma of reductionism, concerns the scientific approach most used by biologists and biotechnologists. This dogma draws attention to the criticism which deals with the idea that biotechnology is inclined to use the "reductionist and mechanist image of science" and that through this everything is reduced to "biological data" (Ibid.).

The second is the dogma of doing which refers to what is practically possible in terms of technology. The dogma of doing is associated with Heidegger (1889-1976) defining technology as a way of revealing "what was already there" (Sabatino, 2007). Sabatino notes that it is only "recently (that) informational patterns have been brought out of the secrecy of ages and translated into a language of intelligibility that can be deciphered through the lens of science and made available to human scrutiny and manipulation" (Sabatino, 2007, p69). The "secret" Sabatino was referring to was knowledge around the genetic code. As far as this dogma is concerned the criticisms have to do with the ethical level, involving indiscriminate use of the new knowledge enabled by technology. According to the criticisms it is necessary to constrain biotechnological applications in order to keep humankind away from dangerous unethical temptations. This draws attention to the new technologies to protect human and environmental health that are often rejected because of political and cultural conservatism (Borbone, 2009).

The third dogma i.e. the dogma of denaturalized nature is linked to an image created by the adversaries of biotechnology and science. Borbone (2009) expressed this as follows: Biological =

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infinity links up to the idea of the unlimitedness of modern genomics and distinguishes it from traditional genetics because of the amount of data that is collected (Allison *et al*., 2009).

natural = morally good; and Artificial = unnatural = morally unacceptable. What these equations are saying is that nature is good. However, it must be recognized that crops that are considered "natural" are the result of millennia of human interference and experiments with nature. Nature was domesticated in prehistoric ages and this process is still continuing today. Even the methods of classical agriculture are unnatural techniques consisting of forced traditional intercrosses where entire genomes have been recombined. Genetic engineering (GE) in contrast inserts a fragment/s of DNA from one organism into the genome of another organism. The criticism concerning this dogma that is most widely come across, is the perception of the indiscriminate use of nature through the creation of genetically modified organisms (GMOs) by unnatural means (Ibid.) which links to the second equation, i.e. artificial = unnatural= morally unacceptable. What is now considered "natural" is in fact not natural at all, thus disempowering criticism concerning contemporary biotechnology practices. The criticisms attributed to biotechnology can thus be seen to be linked to conservative philosophies and epistemologies.

Borbone (2009) further argues that the foundations of people's fears are due to the inadequate involvement of the public in the decisions made about science and its technological applications. According to him, the pros and cons are concerned with the values and life models that a community wishes to follow. In other words the pros and cons of the technology are not only concerned with risk evaluation and whether there are material advantages.

Public perception of biotechnology is extremely complex, as is especially highlighted in controversies around the use of genetically modified organisms (GMOs) such as in genetically modified foods and their consumption. In 1991, the OECD developed the concept of substantial equivalence which states that if the toxicological and nutritional composition and characteristics of genetically modified foods can be compared to the conventional ones, they can be considered as "safe". This also depends on whether the genetic modification process used is considered safe (Strategies for Assessing the Safety of Foods produced by Biotechnology, Report of Joint FAO/WHO Consultation, Geneva, 1991, in http://www.who.int/foodsafety/publications/biotech/en/1990.pdf.) The principle of substantial equivalence is influenced by economic factors rather than by scientific factors. The USA, which is the main GM food producer, has been against the introduction of rules aimed at ranking GMOs on a different level compared to other living organisms, because they claim the principle of equivalence. Millstone *et al.* (1999, p526) criticized this principle by stating that "substantial equivalence is a pseudo-scientific concept because it is a commercial and political judgment masquerading as if it were scientific".

In 1992, the "precautionary principle" was formulated during the United Nations (UN) Conference on the Environment and Development held in Rio de Janeiro ("Rio declaration on Environment and Development" http://www.unep.org/Documents.multilingual/Default.asp?DocumentID=78&ArticleID=1163..) The precautionary principle was instituted to protect the environment. It stated that decisions to use the technology should be based on scientific certainty and the capacity of the state or country. It was argued that the precautionary principle would apply where scientific evidence was insufficient and inconclusive, and if the preliminary scientific evaluation indicated that there were potentially dangerous effects on the environment, human, animal or plant health (Ibid.)

The principle of substantial equivalence is more lenient than the precautionary principle and allows for the commercialization of GMOs. However, it has been strongly criticized because of its basic epistemological shortcomings regarding the analysis and evaluation of risk originating from the use of genetically modified (GM) products (Borbone, 2009). An example is RR soya, which is soya that has been genetically modified so that it is resistant to a herbicide called Roundup. RR soya was commercialized by Monsanto and the herbicide Roundup was produced by Monsanto, highlighting issues of monopolization in the agro-food sector. In 2000 a team of researchers from Belgium showed unexpected and previously unidentified gene sequences that were close to the transgene in the DNA of the soya plant. The reason this made the news is that the Belgian research team accused Monsanto of hiding this information (http://www.pewtrusts.org/uploadedFiles/wwwpewtrustsorg/Fact_Sheets/Food_and_Biotechnology/PIFB_Genetically_Modified_Crops_Factsheet0804.pdf).

The analysis and the evaluation of risk is more complex in the case of the precautionary principle, as the analysis and evaluation is done in statistical terms. Here risk is the main subject with two variables i.e. the probability that an event can happen and the impact that this event can have, determining the risk. However, Borbone (2009) argues that this principle can seriously obstruct scientific research, as the highest levels of science are sometimes reached through taking certain risks, thus making progress possible. With respect to transgenic crops and food, it has been shown that attitudes can range from discrete approval in the USA to rejection by the majority of the European public (Massarani & de Castro Moreira, 2005).

2.2.2. Biotechnology in southern Africa

Traditional biotechnology has been practiced by indigenous peoples in southern Africa for centuries, as in the brewing of local beers such as those produced from sorghum or marulas, and in the mating of cattle to produce particular colour patterns. However, modern biotechnology requires the use of carefully controlled laboratory procedures which are only available as a result of modern science and scientific methods. There are many social and economic problems in southern Africa that could benefit from the implementation of novel technologies in agriculture using biotechnology. However, in the SADC region high levels of poverty, the absence of adequate infrastructure, lack of availability of chemicals and fertilizers, lack of equipment and facilities, limited access to markets and the lack of communication between researchers and farmers and the lack of human resources to support the expensive undertaking of biotechnology (Brink *et al*., 1998; George, 2009; Mnylwa & Mugwagwa 2005), restrict the successful implementation of genetically modified (GM) crops.

The Food and Agriculture Organization (FAO, 2005) estimated that Africa's projected annual rate of population growth of 2.8 percent would lead to a doubling of the size of Africa's population in 25 years (in Eicher *et al*., 2006). Food insecurity is a prevalent issue in Africa which is exacerbated by biotic and abiotic factors such as pests, diseases, drought and floods, together with political instabilities (Machuka, 2001; Mnylwa & Mugwagwa 2005). Biotechnology can be considered as a direct solution for improving agricultural productivity (Brink *et al*., 1998; Eicher *et al*., 2006; George, 2009) especially since a number of transgenes conferring diverse traits such as high protein content, improved nutritional compounds, disease, insect and virus resistance, herbicide resistance and salt and drought tolerances have been successfully transferred into crop varieties through transgenic biotechnology (Lu and Yang, 2009). All fall within the area of agricultural and plant biotechnology (APB).

However, several researchers have publicized concerns about the biosafety of the technology as well as the suitability of the technology in an African setting (George, 2009; Machuka, 2001; Mnylwa & Mugwagwa, 2005). These biosafety concerns focus on APB products for human use and consumption, the environmental safety of APB and the possible exploitation of African nations by international commercial industries assisting in APB development (Brink *et al*., 1998; George, 2009). The environmental safety issues include direct and indirect effects of toxic transgenes to non-target organisms; influence of GM plants on biodiversity ecosystem functions and soil microbes; and extreme concern about the issue of cross-pollination and gene transfer from genetically modified plants to weed-related species (Lu and Yang, 2009).

Furthermore, there are other concerns concerning biotechnology and science and these have to do with how they are taught. According to Ogunniyi (1988) science educators have started becoming aware of the need to relate science to learners' societal and cultural environments to minimize possible conflicts that may arise between the learners' view of the world and that of science. This is an important consideration especially as an African worldview and African culture may be suspicious of western modern science, as it does not fit in with African customs and traditions. Ogunniyi (1988) even goes as far as to state that in a linear theory of change, traditional and scientific modes of thought are denoted as opposites (Ogunniyi, 1988). Urevbu (1984) and Ogunniyi (1986) have pointed out that science curricula do not reflect the cultural background of the African learner because they are modelled on those from the West. The technology can lead to uncertainty and confusion about the knowledge associated with it (Mugabe, 2005). This new knowledge may be contradictory to traditional religion and the African mode of understanding the environment (Ogunniyi, 1988). The response of African governments concerning ethical, environmental and economic issues related to this technology are also often uncertain and confused (Mugabe, 2005) and do not allow the development and application of biotechnology in some southern African countries. According to Mayet (2005) several African countries have imposed restrictions, including bans on the import, distribution and commercial growing of GMOs. These bans formed part of a continent wide response to the risks posed to human health, the environment and traditional farming practices by GMOs (Ibid.).

The above mentioned concerns have had a negative impact on the progress by African governments to develop legislations, policies and regulatory frameworks for the integration and implementation of APB (Brink *et al*., 1998; Machuka, 2001; Egwang, 2001). Also, the development of APB has mainly focused on crops of high economic global importance such as maize, rice, wheat, soybean, tomatoes and potatoes. The development of these technologies has been seen as lacking an "African focus" (Machuka, 2001; Egwang, 2001; Eicher *et al*., 2006) because agricultural and plant species such as sorghum and cassava, important specifically to Africa, have little appeal for international industries because of their low socio-economic status and contribution to the international economy (Brink *et al*., 1998; Mnylwa & Mugwagwa, 2005). In addition, the GM crops are originally researched and developed for specific conditions not usually experienced in Africa, and are not necessarily suitably adapted to the harsh African climate and poor soil conditions of Africa (Thomson 2008; Brink *et al*., 1998). However, despite this, according to the Food and Agriculture Organization of the United Nations (FAO) in 2007, approximately 12 million farmers benefited from GM crops, with 92% of those farmers being resource poor farmers from developing nations, including many African nations (http://www.fao.org/biotech/inventory_admin/dep/country_rep.asp?country+BWA). Thomson (2008), writing in 'The Philosophical Transactions of the Royal Society. Biological Sciences' which has a high impact factor and addresses theme issues on cutting edge topics across biological sciences, urged that new efforts should aim to improve biotechnological research and crop improvement in African countries, to develop appropriate crop varieties that can benefit small-scale subsistence and large-scale commercial farmers alike. This supported Paarlberg's (2006) argument that drought tolerant traits transferred into varieties of maize, wheat, rice, sorghum or millet would be far more valuable to poor African farmers than the insect and herbicide resistant varieties already released.

2.2.3. Biotechnology in South Africa

In southern Africa, South Africa plays a leading role in biotechnology (Mwale, 2005). South Africa has a history of engagement with traditional biotechnology which has led to one of the largest beer brewing companies in the world (South African Breweries). It has also led to the development of excellent wines (Ngubane, 2001). In addition to alcoholic beverages, biotechnology has also led to the utilization of its natural plant and animal diversity, for example, in the protea and kwagga breeding programmes.

Modern biotechnology involves manipulating DNA, and refers to the use of genetically modified (GM) organisms in agriculture and industry (Campbell and Reece, 2005). South Africa is now the 8^{th} highest producer in the world of genetically modified foods, planting more than 1.8 million hectares of GM crops in 2008 (GMO Indaba, 2009). South Africa is at the forefront of research on crops of both economic and cultural importance. These crops include various cereals: maize, wheat, sorghum, millet and soybean; vegetables: cassava, yam and sweet potato; various other economically important fruits and flowers (Brink *et al*., 1998). GM crops are now grown by both commercial and small-scale farmers. APB techniques include tissue culture programmes established for application in root and tuber crops and ornamental and horticultural crops, genetic engineering projects (both public and private) for the commercial growth of insect-resistant maize and cotton and herbicide-tolerant soybeans and cotton. Marker-assisted selection is also applied in maize and small-grain breeding. Molecular diagnostics and markers are used for plant disease diagnosis and biological nitrogen fixation is applied in soil fertility improvement by using legumes and inoculants.

The reason why South Africa exhibits the greatest plant genetic engineering (PGE) and plant breeding (PB) research output of all the SADC nations may possibly be because of its economic standing in relation to the other nations of the SADC and the fact that biotechnology curricula are established in various tertiary education institutions. Moyo *et al.* (2011) reported that South Africa is the hub of PGE and PB research in southern Africa because it is one of the highest output nations of PGE and PB research on the African continent.

2.2.4. Legislations, policies and regulatory frameworks in South Africa

South Africa has developed APB to a position where infrastructure and regulatory frameworks are adequate to facilitate Plant Genetic Engineering (PGE) as well as the commercialization stage of GM crops. South Africa has a legally-binding Genetically Modified Microorganisms Act (Act no.15 of 1997) amended in 2006 and the country adopted the National Biotechnology Strategy in 2001, which created a policy framework to establish incentives for the biotechnology sector. This strategy led to the establishment of Biotechnology Regional Innovation Centres (BRICs) throughout the country. These centers functioned to conduct and fund biotechnology research and to introduce initiatives to encourage international partnerships. The BRICs are now known as the Technology Innovation Agency (TIA or the Agency). The TIA was established in terms of the TIA Act, 2008 (Act No. 26 of 2008). The objective of the TIA is to encourage technological innovation in order to improve economic growth and the quality of life of all South Africans. The formation of the regulatory framework permitted the commercialization of existing knowledge from biotechnology research (Brink *et al*., 1998). The South African Department of Science and Technology's (DST) ten year innovation plan (2008-2018) also aims to drive transformation towards a knowledge-based economy, in which the construction and propagation of knowledge leads to economic benefits. One of the grand challenge[3] areas of the DST, the "farmer to Pharma" value chain (2008-2018), aims for South Africa to become a world leader in biotechnology and pharmaceuticals, based on the nation's indigenous resources and expanding knowledge base. With this in mind, it is important to consider Robeck's (1994) opinion (cited in Jegede, 1997, p5) as he feels that the "claim to superiority of western science conflicts with the possibility of addressing indigenous knowledge with respect". This opinion leads to the many questions covered in the literature regarding indigenous knowledge becoming part of western modern science and belonging to the global scientific community and to global scientific practice.

[3] Other challenge areas not in the scope of this project include: Space Science and Technology; Energy security through the promise of "hydrogen economy"; Global climate change science with a focus on climate change; and human and social dynamics.

The hoodia plant is a good example of the use of indigenous knowledge and resources for economic gain in southern Africa. *Hoodia gordonii* is a thorny succulent naturally occurring in the Kalahari Desert, which spans Botswana, Namibia and South Africa. It was traditionally chewed by the San people of the desert on long hunting trips because of its hunger-suppressing properties. It was later used by the Nama people for its many medicinal properties: it lowers blood pressure, fights cholesterol, prevents cardio-diseases, increases blood circulation, and can be used to bring down blood sugar content in diabetics (http://www.africanagricultureblog.com/search/label/hoodia).

The appetite-suppressing properties have created a frenzy of demand for hoodia in the world dieting industry. South Africa's Council for Scientific and Industrial Research (CSIR) isolated and identified P57, the active ingredient, and patented it in 1996. The British firm Phytofarm later developed and commercialized it. Phytofarm signed a royalty deal with the San tribesman. The San will therefore, benefit through benefit sharing, but also through training to become active members in the commercialisation process of the hoodia plant (http://www.africanagricultureblog.com/search/label/hoodia).

All the strategies of the DST mentioned above have the potential to allow South Africa to make a significant mark in biotechnology. However, scientists working in this field face many challenges such as funding shortages and regulatory hurdles when it comes to biotechnology crop expansion. The DST’s ten year innovation plan is to support the individual scientists and farmers. The DST’s vision is “to create a prosperous society that derives enduring and equitable benefits from Science and Technology”, and their mission is “to develop, coordinate and manage a national system of innovation that will bring about maximum human capital, sustainable economic growth and improved quality of life for all” (DST website ISBN: 978-0-621-39697-3).

2.2.5. Biotechnology in Namibia

Namibia contains two deserts, the Namib and the Kalahari. It is one of the driest countries in Sub-Saharan Africa. The combination of dry, sandy soils and a shortage of water make it difficult to grow crops throughout the country. Since gaining independence from South Africa in 1990, Namibia has maintained political and economic stability (Ipinge, 2007). Prior to 1990, there were no crop research activities. The Government of the Republic of Namibia cognisant of the significance of crop improvement potential for rural farming communities approached SADC and International Crops Research Institute for the semi-Arid Tropics Regional Programmes on Sorghum and Millets Improvement (ICRISAT) for assistance to initiate a crop improvement programme (Ipinge, 2007). In 1992 the government's National Assembly established the University of Namibia, where much of the country's scientific research and training occurs. Much of the focus at UNAM has been on gaining critical skills and technical expertise so the laboratories are mostly for teaching and they are generally not strictly research laboratories. However, the North of Namibia is a malaria area, so there is a Malaria Research Laboratory at UNAM. Research is on plants according to information from traditional healers. These traditional healers are known to use certain plants for example, to treat malaria patients. The plants that are believed to contain anti-malarial properties are evaluated for efficacy, safety and bioavailability of the compounds. Other research involves looking at other plant species for medicinal and nutritional benefits (http://sciencecareers.sciencemag.org/career_magazine ???/previous_issues/articles/2011).

In Namibia the types of APB techniques that are used include tissue culture for producing root and tuberous plants vegetatively, and for micropropagation and disease elimination. Serological techniques and biological nitrogen fixation are applied for legumes. Plant breeding objectives of historic importance include resistance to insects and diseases, tolerance to biotic and abiotic stresses and the development of new crops (Callaway and Francis, 1993)

General crop productivity in Namibia is low due to the combined effect of persistent and recurring droughts and poor soil fertility. Pearl millet is Namibia's most important staple crop and it is a priority in the breeding programme. The following crops are grown and evaluated in plant breeding programmes: cotton, cowpea, groundnut, Bambara groundnut, maize, sweet potato, sorghum, rice and cassava. These breeding programmes concentrate on resistance to abiotic and biotic stresses, and quality traits. These crops are important in food security issues and crop diversification. These breeding programmes provide the farming communities with a range of crop options, and through them farmers are empowered to mitigate the effects of drought and erratic rainfall (http://gipb.fao.org/web.FAOPBBC/Downloads/FullRepoprts/FR-NAM.pdf).

In 1985 there was no scientific research dedicated to crops or plant breeding, as all efforts were geared towards livestock research. Livestock is the country's number one foreign exchange earner (Ipinge, 2007). From 2005, the biotechnology practices have concentrated mainly on the generation and acclimatization of *in vitro* plantlets of sweet potato and cassava through tissue culture. The application of biotechnology in crop improvement is limited except for academic purposes at UNAM. In the Department of Biology in UNAM's Faculty of Science biotechnology research includes special emphasis on genetic characterization and marker assisted selection of pearl millet, sorghum, and other legumes. This research is not, however, considered as part of the national plant breeding capacity development programme (http://gipb.fao.org/web.FAO-PBBC/Downloads/FullRepoprts/FR-NAM.pdf).

Namibian research teams together with teams from South Africa and Europe have worked on projects investigating the development of insect resistance in important African crops such as Bambara groundnuts and Marama beans and fungal resistance in millet (ABSF AFRICA, 2009). Biotechnology research and development in Namibia is limited, beyond the projects mentioned above. The Namibian Biotechnology Alliance (NABA) is working really hard to promote and research biotechnology.

With the formation of the Hoodia Growers' Association of Namibia (HOGRAN) the commercialization of hoodia took off in Namibia in 2006. This involved the commercial growing and harvesting of the *Hoodia gordinii* plant, and it has started to address poverty and at the same time create opportunities for Namibian people to become entrepreneurs (http://www.africanagricultureblog.com/search/label/hoodia). This is in accordance with "Vision 2030" which is a policy framework for long-term national development which requires developments in science and technology to produce a knowledge-based economy in Namibia (http://www.npc.gov.na/vision/pdfs/Summary.pdf).

2.2.6. Legislations, policies and regulatory frameworks in Namibia

In Namibia the Biosafety Bill was passed in 1999 and since the signing of the Cartagena Protocol on Biosafety in 2000 and the endorsement thereof in 2005, biotechnology has gained ground. The Namibian Biotechnology Alliance (NABA, 2004) is a forum that is involved in developing and promoting biotechnology use and research within Namibia. It developed the National Biosafety Framework in 1998 and has done research into "Awareness in Biotechnology and Biosafety" and "Identifying the agricultural needs that could be solved through Biotechnology" (NABA, 2004). The Ministry of Agriculture, Water and Rural Development administers the Biotechnology research policy for Namibian APB development. Namibia does not import any genetically modified products and has a strict border control which requires a certificate, possible tests and rejection, if the product is found to be genetically modified (http://www.fao.org/biotech/inventory_admin/dep/country_rep.asp?country+NAM.). This rejection is possibly due to the fact that the seeds of these genetically modified grains could be planted and if 'out crossing' occurs with other non-GM grains, the future harvests will be contaminated, which could be a problem when considering exports to countries with a ban on GM foods. According to Mayet (2005) several African countries imposed bans or some form of restriction on import, distribution and commercial growing of GMOs. This included Namibia, where the Namibian government rejected GM maize in 2002 for food aid and accepted non-GM wheat.

The Food and Agriculture Organization (FAO) of the United Nations commissioned a national plant breeding and related biotechnology capacity survey in various countries including Namibia between 1985 and 2005. The purpose of this was to establish the status of plant breeding efforts so as to advise the Governments on ways to strengthen agricultural sciences. The results of the FAO Plant Breeding and related Biotechnology capacity survey for Namibia include: no private sector institutions engaged in crop improvement activities; private seed companies simply supply seeds and fertilizers to the general public; the public sector is the only driving force behind plant breeding and biotechnology; and the Directorate of Agricultural Research and Training (DART) remains the dominant player in crop improvement activities.

Furthermore, the application of biotechnology in crop improvement is very limited, and is mostly tissue culture applications.

The Directorate of Agriculture and Training (DART) in Namibia considers the following factors to have limited its success in plant breeding: inadequate number of breeders; lack of knowledge about recent plant breeding techniques; lack of support from the international community; inadequate access to the latest literature and inadequate experimental field conditions, and a lack of trained human resources (Ipinge, 2007).

2.2.7. Summary to section on the nature of biotechnology

From the discussion on the literature relating to the discipline of biotechnology and the status of biotechnology in both South Africa and Namibia, it can be seen that the development and application of biotechnology is valuable and important. With the apparent lack of biotechnology capacity among scientists in the SADC region, in both the theory and applications of biotechnology, it is vital that the skills required for establishing biotechnology knowledge should be promoted through capacity training at the tertiary institutions. Tertiary education can contribute to this capacity development by developing biotechnology courses which explicitly facilitate expertise in these fields. One of the ways to do this is by providing a curriculum which recognizes differences in worldview and issues of epistemology, because it has been established that epistemological barriers play a significant role in effective teaching and learning in multicultural situations (Stanley & Brickhouse, 2000; Cobern, 1996).

2.3. The nature of epistemology

The word 'epistemology' as defined by the Merriam-Webster Dictionary, is from the Greek ἐπιστήμη (epistēmē), meaning "knowledge, understanding", and λόγος (logos), meaning "study of". It is thus the branch of philosophy concerned with the nature and scope of knowledge. Epistemology concerns the question of what knowledge is, and how it is acquired. Furthermore, it questions to what extent it is possible for a given subject or entity to be known. Hofer (2006) argues that beliefs that people hold about knowledge and knowing, termed "personal epistemology" (Hofer and Pintrich, 2002 in Hofer 2006, p86) are related to learning and achievement. Personal beliefs about the nature of knowledge and how humans develop knowledge form their epistemological beliefs (Hofer, 2006). In education it is believed that these personal beliefs are closely related to how students learn. Much of the contemporary understanding and discourse on teaching and learning is related to the developmental theories of Piaget (1964, 2003). These theories provide the basis for how learners acquire knowledge through a personal process of internal mental construction. 'Constructivism' describes how new ideas are built on previously held conceptions (Ausubel, 1960). Constructivism grew from the term 'personal constructs' which was postulated by Kelly in 1955, and it emphasizes the idea that "individuals construct knowledge for themselves through construing the repetition of events, and that knowledge is individual and adaptive rather than objective" (Geelan, 1997, p17). Maddock (1981) described this as 'cognitive construction'.

In developing countries, education has been seen as a key to development, especially with regard to science and technology. However, education as it is understood in relation to western models of formal education has not been very successful in African countries (Ogunniyi, 1995; Jegede, 1998). Research which has sought to understand this has largely drawn on "worldview theory" (Cobern, 1996). The recognition of the impact of worldview on teaching and learning (T&L), along with social theories of learning (Vygotsky, 1979), has popularised the notion of 'socio-cultural' constructivism. There is evidence of a link between students' epistemological beliefs and the way they learn and the outcomes they achieve (Kang 2008). According to Kang (2008), research is also beginning to show that the teachers' views influence teaching in terms of content and the way in which they teach and assess. In other words, besides their training, teachers' personal beliefs also influence the way they teach. So, in the same way as for learners, teacher's personal epistemologies impact on their teaching philosophy and pedagogical practice. Kang (2008), whose research focused on identifying possible connections among teaching goals, epistemological beliefs and teaching actions, argued that people see science knowledge as human construction. The traditional view of science has been the realist view (von Glasersveld, 1989) where science is thought to represent the ultimate reality or truth about the Universe. Furthermore, Cameron (2007) highlights that scientists and science educators who have been steeped in a Universalist view of science called "western modern science" (WMS) are often not aware of the hegemonic nature of this knowledge or of positivism. Kang goes on to say that we have personal epistemologies in two dimensions, the rational epistemological dimension, which represents knowing either as active construction of meaning or as receiving knowledge, and the ontological dimension which sees science as a collection of facts or information, or science as the product and process of inquiry and thinking (Kang, 2008).

The theory of epistemological beliefs and how they develop i.e. their sequential development (Perry, 1981 in Tanase and Wang, 2010) involves firstly, initial beliefs of learning (the construction of knowledge); secondly beliefs related to teaching (the facilitation of the construction of knowledge); and thirdly personal epistemological beliefs (the nature and validity of knowledge) (Tanase and Wang, 2010, p1239). Perry proposed that personal epistemological beliefs change, and do so in synchronous order according to stages. Magolda (1996) and Khun (2000) supported this synchronous development of epistemological beliefs. The stages categorized in their studies (as cited in Tanase and Wang, 2010, p1239) were: "absolute knowing (knowledge is viewed as certain; acquiring knowledge is important), transitional knowing (some knowledge is seen as uncertain and understanding of the knowledge becomes important), independent knowing (knowledge is mostly viewed as uncertain and one's own thinking is valued), and contextual knowing (knowledge is determined contextually)".

There are different categorization systems for personal epistemological beliefs and how epistemological beliefs can change (Perry, 1970; Tanase and Wang, 2010; Brownlee, 2001; Schommer-Aikens *et al*., 1990, 2000). These categorization systems can be used to provide a clearer understanding of conceptual changes in teachers' epistemological beliefs. Research has shown that different teachers and at different stages in their careers, use different teaching strategies based on changing epistemological beliefs about teaching (Tanase and Wang, 2010). For example, shallow-processing teaching was used by those who trusted the authority as a source of knowledge, while deep-processing teaching strategies were used by those who believed that knowledge was derived through reasoning (Ibid.)

From the discussion above, in terms of this research study, it can be seen that the aspect of epistemology plays an important role in teaching and learning.

2.3.1. The epistemology of science

Given the large amount of information and knowledge produced through the many areas of science associated with biotechnology applications and skills as described in section 2.2 earlier, it is important to consider the epistemology of science. In the context of biotechnology, Davidson *et al.* (2002) explain that when studying cellular control mechanisms in genetic development in organisms, one must learn the inputs and outputs throughout the genomic regulatory system to understand why and how the developmental process occurs. Davidson *et al*. (2002) state further, that to understand where a protein sequence comes from one must know the DNA triplet code as it is not possible to understand development from an informational point of view without unravelling the underlying regulatory networks. In science there is a tight connection between theory and experiment: the epistemology of science is thus based on the scientific method. The life sciences for example, rely on predictive models where legitimacy is based on the data (Chen *et al.,* 2005). The epistemology of science thus places demands on scientific research content with Dougherty and Braga-Neto (2006) saying that it is the predictive capacity of science that gives science its value.

According to Driver *et al.* (1996) images of science are the ways in which an individual thinks about the purposes of science, the nature of scientific knowledge, and the role of scientific investigation. In an article using 11 case studies, Ryder and Leach (1999) looked into the impact that students' images of science have on their activities in project work, and the influence project work has on their images of science. They concluded that the kinds of teaching and learning activities used can promote the development of students' images of science, and that student views about the epistemology of science can have a major impact on student activities during investigative projects.

2.3.2. Techno-epistemology (Epistemology associated with technology)

In the 1980s, the outcomes of social studies in technology and the philosophy of technology were debated by science and technology educators, and the nature of technology as a way of knowing (epistemology) in its own right was put forward. This was driven forward once so-called science, technology and society (STS) curricula were proposed which focussed on the different roles of science and technology in society (Van Eijck and Claxton, 2009). Cobern (1996) points out that science provides us with technology which in turn increases scientific knowledge. Van Eijck and Claxton (2009, p224) also point out that technology as a universal way of human knowing "is apparent in every single culture irrespective of the existence of the epistemology of science". However, technology cannot be reduced to a "single truth" or "justified true belief" that is applicable in every socio-cultural setting, because technology as a way of knowing is concerned with culturally specific human practices based on specific environments (de Vries, 2005). Human activities are centred on their needs which they fulfil through interacting with their environment. As such, this way of knowing and the knowledge associated with it is inherent in the relationship humans have with their environment. Van Eijck and Claxton (2009, p218) argue that technology therefore presupposes unique epistemologies that have to do with the application of skills in the environment. They refer to this as a "techno-epistemology". They claim that this unique way of knowing is overshadowed by scientific epistemology, although technology has many human practices, other than science, which make it epistemologically unique as it arises from a need to interact with the environment as a feature inherent to human praxis (performance and application of skills). As knowledge in praxis, technology is inherent to the continuously unfolding transaction between humans and the environment they collectively modify with respect to their needs (Van Eijck and Claxton, 2009). Human activity which takes into account both the collective nature of human life and the cultural-historically determined transaction with the environment is the unit of analysis of technology (Ibid.).

The word "technology" can be used in a number of contexts. It is taken from the Greek word techne (τεχνε) meaning art, skill, craft (tekton, "builder") and refers to the study of manufactured articles. However, from the above discussion, it is apparent that technology is a collaborative enterprise and has a social component. Therefore to understand technology and its inherent epistemology (techno-epistemology) it requires taking cultural diversity into account because technology as a way of human knowing is bound up with culturally specific human practices.

2.3.3. Traditional Ecological Knowledge

Science educators have been challenged by learning theories such as constructivism, and by philosophical studies that have highlighted relativist notions of “truth”. Instead of seeing science as a universal way of knowing, there are many who adopt a cultural perspective about knowledge and learning. These scientists have moved the borders of scientific inquiry by extending their enquiry into the traditional knowledge and wisdom of indigenous practices. By doing this they have formalized a branch of biological and ecological science that has become known as traditional ecological knowledge (TEK) (Snively and Corsiglia, 2000). This is a term coined to describe knowledge attained through time and patient observation of the natural world. If science is understood as an exploration/explanation of nature, TEK can not only be regarded as science in its own right but it also can be seen to have ‘science’ in it. According to Snively and Corsiglia, TEK can be thought of as either the knowledge itself, or as documented “ethno-science” enriched by the analysis and explanation of science specialists. They see science as human knowledge construction and claim that TEK should be regarded as science. However, some researchers for example, Van Eijck and Claxton (2009) argue that TEK may be out of the sphere of western science as it is defined, i.e. knowledge that’s developed through evidence and experimentation.

In the term Traditional Ecological Knowledge (TEK), “Traditional” refers to a cultural continuity transmitted through social attitudes and beliefs derived from historical experience. However, as societies or communities change over time and adapt to their environment by adopting new practices and technologies the typical definition of “traditional” becomes difficult to formulate. The term “ecological knowledge” is also difficult to formulate, especially since ecology is defined as a branch of biology in the discipline of “western science”. In the science education literature, science is commonly referred to as “western modern science” (WMS). The ‘western’ refers to the geographic location of the origin, development and practice of this body of knowledge and the modern serves to distinguish it from ancient and medieval science (Snively and Corsiglia, 2000). However, to those outside of the culture of WMS, it is hegemonic, with a particular epistemological and ontological basis (Cameron, 2007).

The knowledge and understanding of nature held by indigenous people is also (besides being referred to as TEK), categorized as 'non-western nature-knowledge' (Lewis and Aikenhead, 2001) or 'indigenous knowledge systems' (IKS) (Cobern and Loving, 2001). In the South African education system these 'other ways of knowing' are referred to as indigenous knowledge systems (Odora-Hoppers, 2001). These include the beliefs and explanations that come from individuals' socio-cultural background. As mentioned in Chapter 1, there are different aspects to IKS. These aspects include the use of traditional building and farming methods, the use of plants for medicinal purposes, and the traditional technology and customs in which science is embedded, such as the brewing of local beers. Other aspects of IKS include other forms of knowledge, e.g. traditional folklore and indigenous metaphysics (Cameron, 2007). These aspects of IKS form part of the whole essence of African spirituality (Ibid.).

Some authors prefer the term indigenous knowledge (IK) to TEK as it puts the emphasis on indigenous people. TEK and/or IK refers to knowledge acquired over thousands of years of human contact with the environment, and sometimes this is information that is passed on orally and it is shared only if it will not be used for gain (Snively and Corsiglia, 2000). Setiloane (1998) describes it as being passed on particularly through the grandmothers to their grand children. The IKS that is probably of most interest to science educators is that which has 'science' in it.

2.3.4. African epistemology

African epistemology is characterised by strong interpersonal relationships, communalism and spirituality (Bakari, 1997; Mbiti 1970, 2006). This epistemology places emphasis on ethics and morality, symbolic imagery, self-awareness and tradition (Bakari, 1997). According to Higgs (2007) African identity has both geographical and cultural factors: these include language, ethnic and religious identification. Community and belonging to a community of people is of central importance in African philosophy. According to Higgs (2007) in tertiary education institutions, research that focuses on the African community aims to integrate indigenous African knowledge systems with modern knowledge systems while simultaneously exposing indigenous communities to scientific knowledge production and dissemination, founded on indigenous cultural and social values. There are authors such as Lewis and Aikenhead (2001) who are opposed to including TEK with western science as they feel it would be a ‘Pyrrhic victory’ (Lewis and Aikenhead, 2001, p4). The reasons given for this are that TEK would lose its uniqueness and be lost within the discourse of science and that it could then possibly be seen as a gesture of cultural inclusiveness not a scientific discourse in itself (Cobern & Loving, 2001; Lewis & Aikenhead, 2000). In countries where people of European descent coexist with indigenous people, especially where the indigenous people are in the minority (United States, Canada, Australia, and New Zealand), their systems of indigenous knowledge have been almost or completely destroyed due to them having undergone a “culticide” through the colonizer’s educational systems (Van Eijck and Claxton, 2009). Higgs (2007) argues that in Africa, knowledge is generally passed on verbally, where it is more about preserving existing knowledge and wisdom from the past, rather than generating new knowledge. It is not given much attention in formal science classrooms (Snively and Corsiglia, 2000). Van Eijck and Claxton (2009) encourage science educators to overcome trends in science curricula that discourage indigenous minorities in sustaining their worldviews and they encourage students to consider how technology-based topics reflect moral principles and virtues that are part of their lives. Higgs and Van Wyk (2006) urge that higher education should be a natural process by which members of the community gradually acquire skills, knowledge and attitudes appropriate to life in their community. African identity highlights an intricate relationship between education and social development. Students who are able to graduate with an appreciation of indigenous geographical and cultural factors in fact could make a contribution to society because they would have “traditional” intellectual skills as well as those that come from formal education (Higgs and van Wyk, 2006).

2.3.5. Summary to section on the nature of epistemology

From the discussion on the literature it can be seen that there are epistemologically different ways of knowing and because this study is interested in worldview concerns that may affect "epistemological access" in terms of the biotechnology curriculum, it has been important to discuss each of the different epistemologies that could be associated with biotechnology teaching and learning. Teaching and learning activities can promote the development of students' images of science and student views about the epistemology of science can have a major impact on their learning. Furthermore, because technology as a way of human knowing is bound up with culturally specific human practices, understanding technology and its inherent epistemology (techno-epistemology) requires taking cultural diversity into account. It follows then that IKS can be included in both science as a discipline and in science education. Finally, as an African identity highlights a complex relationship between education and social development, students who develop an appreciation of African science, and techno-epistemologies will be better placed to make a contribution to society because they would have "traditional" intellectual skills. With the effect of globalization a greater demand is placed on the use of science and technology as the basis for improving the quality of life and local tertiary education institutes provide the means to achieve this meaningfully in the local context.

2.4. The nature of tertiary science education

In the 22 years that have elapsed since Nelson Mandela's release from prison, education in South Africa has gone through massive reform to address the inequalities of the past, as is the case in Namibia since their independence in 1990. Cherry (2010, p728) points out that "since 1994 the government has in theory been committed to ensuring that 'blacks' (a generic term it uses to mean all people not classified as white under apartheid) have had improved access to higher education and research, but this has turned out to be difficult to achieve particularly in science". Cherry (2010) ascribes these difficulties to the fact that many black schools did not offer maths and science in the apartheid era and, to a lesser extent to teacher shortages. The lack of success in science education in Africa has provoked a good deal of research especially with regard to African culture and the different ways of knowing related to this.

The constructivist notion of the importance of prior learning is at the heart of the national curriculum, created in the years following 1994. Both the South African and Namibian population are made up of a vast diversity of cultures evidenced by the fact that both countries have many different official and recognised regional languages and ethnic groups i.e. South Africa has 11 official languages and 4 ethnic groups and Namibia has 1 official language, and 9 recognised regional languages, with 12 different ethnic groups. This cultural diversity leads to a wealth of 'different ways of knowing'. These ways of knowing are associated with different customs and belief systems. In developing the new curriculum, the South African Department of Education (2003) acknowledged the need to recognize and ascribe value to these ways of knowing. Odora-Hoppers (2002) focuses on the role of IKS for the process of creative and transformative change in education as she sees a complementarity between indigenous and western knowledge systems.

Aikenhead (1996) has argued that science is a subculture of western science and to emphasize the cultural makeup of science, some authors represent science with the acronym WMS which means "western modern science" (Ogawa, 1995). The opposing philosophical presupposition called "the universality of science" refers to science as uncovering knowledge and solving problems regardless of culture, race and gender of the scientist (Stanley and Brickhouse, 1994). Modern science education in Africa is closely linked to its colonial past (Jegede, 1997). The independence era of most African countries coincided with the early years of science education research in southern Africa, and according to Urevbu (1987) the curriculum was loaded with facts and information considered essential to technological development in Africa. According to Jegede (1997) the science teaching curriculum did not identify context-specific issues related to what science could do for African countries and it ignored the socio-cultural backgrounds of the learners. However, culture has been argued to affect achievement in schoolwork, as school learning and performance are influenced by complex social, economic, historical and cultural factors (Ogbu, 1992).

In southern Africa, science curricula at the tertiary education level are still based on WMS. However, the diversity of students results in a multiplicity of ways of knowing because of their different socio-cultural backgrounds. The new knowledge they are exposed to is constructed on what they already know, and this has been shaped by their socio-cultural environment. Many of the students have strong fundamentalist religious beliefs (Cameron, 2007). The presentation of ‘facts’ and ‘concepts’ in the science classroom, if unmediated in terms of these beliefs could result in cognitive and psychological conflict for these learners. It is thus important to recognize prior knowledge and the existence of other ways of knowing with regards to learning.

Science-technology-society education (STS) comprises an interaction between science and technology, between science and society and the interaction between technology and society (Jegede, 1994). Jegede (1994) argues that a student-oriented multiple-vista conceptualization of science education fits in with a cross-cultural approach to science education. He proposed that STS education include societal issues related to science and technology or philosophical, historical, or societal issues within the scientific or technological community. This could support cross-cultural teaching in non-western countries such as those in southern Africa. In South Africa and Namibia there has been progress in the education field in terms of recognizing the importance of prior knowledge and the existence of other ways of knowing, especially with regard to IK, and its inclusion or recognition in the science curriculum in South Africa (Odora-Hoppers, 2010); and in Namibia where the science curriculum is being improved for biotechnology capacity through Vision 2030 (Ipinge, 2007). Vision 2030 is the policy framework for long-term national development which requires developments in science and technology to produce a knowledge-based economy (http://www.npc.gov.na/vision/pdfs/Summary.pdf). Most of the topics of interest in Namibia include plant species for medicinal and nutritional benefits i.e. relying on indigenous knowledge to be incorporated in the curriculum for biotechnology capacity development. According to Ipinge (2007) if Namibia is to reach the goals set through Vision 2030, deliberate and concerted efforts should be made in investing in human resource capacity building which should be through training at the tertiary education level.

According to Laugksch (2000), the term ‘scientific literacy’ in the context of education equates to the development in a person of the ability to understand the nature of scientific knowledge, to use science in solving problems, and to appreciate the connections between science and technology, and between these two and society. Students of different cultural backgrounds may interpret science concepts differently according to their prior knowledge, indicating that teachers should prepare a science curriculum suitable for use in a multicultural classroom by using the prior knowledge that the students bring to class. Snively and Corsiglia (2000) argue that the curriculum should recognize a community's indigenous knowledge or worldview in a way that creates a desire to know western science, i.e. by including IK and WMS content to study certain fields of interest more thoroughly, thus enriching understanding of the environment in a sustainable way. It has been shown in a number of studies that references to examples of indigenous science results in increased interest and participation by African learners (Jegede and Okebukola, 1991; Naidoo, 2001; Brown *et al*., 2006).

Kidman (2010) looked into what an interesting curriculum for Biotechnology education would be (500 Australian students and 35 teachers). The results suggest that the key areas the teachers are interested in, and incorporate into their curriculum, are not always the same as the ones the students are interested in. She claimed that the mismatch was due to the curriculum choice available within a mandated syllabus. Biotechnology is a product of the enterprise of western modern science, and, like other scientific disciplines, is taught around the world and in southern Africa through curricula that have not always been modified according to local contexts. This necessitates developing curricula in accordance to local contexts and making it relevant and accessible to the students.

2.4.1. Globalization

The Organization for Economic Co-operation and Development (OECD) is a unique forum of governments of 30 democracies which addresses the economic, social and environmental challenges of globalization. Globalization is described by the OECD (2007, p23) as the process that is increasing "the flow of people, culture, ideas, values, knowledge, technology and economy across borders resulting in a more interconnected and interdependent world". According to Carter (2005), knowledge is a fundamental resource of globalization; education is a major player in globalization; and neoliberalism[4] is the ideology of globalization. Globalization

[4] The political view that emphasizes the importance of economic growth and asserts that social justice is best maintained by minimal government interference and free market forces (Encarta Dictionary: English (U.K.))

affects countries in different ways, having both positive and negative consequences according to a nation's individual history (OECD, 2007).

McKenna (2012) argues that the university is part of the social world; i.e. it affects and is affected by what happens in society. However, with the effect of globalization the role of the university is increasingly being recognized for the role it can play in terms of the economy, especially with regards to the 'knowledge economy' (Drucker, 1996). According to McKenna (2012, p17) what this knowledge economy entails is "a shift in thinking about knowledge as a set of practices to an understanding of knowledge as a product that has currency". This has led to research at the tertiary education level that is largely valued for its application and its marketability. McKenna goes on to say that a global knowledge economy, could have the potential to limit the development of home education systems. However, the Association of African Universities (AAU) Declaration on the African University in the Third Millennium (2001) calls for "a revitalization of the African University and for a renewed sense of urgency in acknowledging the crucial role it should play in solving the many problems facing [the] continent" (in the Accra Declaration, 2004, p2). Furthermore, the Accra Declaration, (2004) warned against the reduction of higher education to a tradable commodity and cautioned that governments should regulate higher education according to national needs and priorities, while remaining aware of global realities. At the same time the Accra declaration (2004) expressed continued support for the multiple forms of internationalization in Higher Education because of the associated benefits not only for African countries but for all countries involved (Accra Declaration, 2004).

Jegede (1997) argues that science-technology-society (STS) education appears to be the most attractive and viable option for the educational system in an African setting. Furthermore, according to Lederman (1992) there appears to be wide agreement on one of the objectives of science instruction, which is the development of an adequate understanding of the "nature of science" or an understanding of "science as a way of knowing". On the positive side, Jegede (1997) argues that through globalization, improved human resources in the areas of computer technology, biotechnology and science will eventually lead to science integrating into the cultural traditions and practices of Africa. Carter (2005) argues that in the context of science education, while globalization is implicated, it remains under-acknowledged and under-theorized.

2.4.2. Cross-border tertiary education

According to the OECD, internationalization of higher education is described as "the process of integrating an international intercultural and global dimension into the purpose, functions (teaching, research, service) and the delivery of higher education" (OECD, 2007, p23). Internationalization activities apply to cross-border projects and campus-based activities. Cross-border tertiary education falls within educational internationalization and "refers to the movement of people, programmes, providers, curricula, projects, research and services across national or regional jurisdictional borders" (OECD, 2007, p24). The Global Education Digest 2009 reports that one out of every five students from African countries is studying at a South African university (10 168 from Namibia in 2009). According to the study one of the reasons they leave their home countries is because of under-resourced universities (Govender, 2009). UNAM and WITS are the first southern African institutions to consider cross-border tertiary education as a helpful capacity development tool in plant biotechnology. This interest in cross-border education is in the area of the development of cooperative projects and academic exchange programmes. The focus is both on the movement of people i.e. lecturers and students (especially at the post-graduate level); and on curricula and research projects which would result in the development of capacity i.e. in human resources and skills. As such, this could lead to maximizing the effective utilization of existing expertise and to ensuring long term sustainability. The provision of cross-border courses falls within the objectives of the SADC protocol on education, as discussed in section 1.1 in Chapter 1.

The growth of cross-border education worldwide has put quality assurance (QA) in the spotlight. Quality assurance can encourage excellence and protect the lecturers and students involved. In this case it can protect students from bad quality, thus supporting capacity development. It also plays a role in capacity building programmes where the cross-border provider fills in gaps not offered locally (OECD, 2007). However, there are differing opinions on the appeal and value of any international standards or criteria for QA. These opinions include that this might endanger the autonomy of national level systems or that it might contribute to standardisation and not necessarily the improvement of standards.

2.4.3. Cultural border crossing and collateral learning

Science and technology tertiary education in southern Africa is offered in multicultural classrooms where different views of science may be firmly rooted in certain cultural assumptions. This influences how students formulate and solve problems (Stanley and Brickhouse, 2000). Earlier discussion on worldview has illustrated the complexity of the construction of scientific concepts in the context of southern Africa where there are many ways of knowing.

Studies conducted in South Africa and other parts of the world have identified that worldview differences can lead to barriers to learning (Cameron, 2010; Prosser and Trigwell, 1999; Cobern, 1996). Two theories which emanate from the worldview theory to explain how students move between their everyday life worlds and the world of science and how they deal with the conflicts that may arise are border crossing (Aikenhead, 1996) and collateral learning (Jegede, 1995). Students in both developed and developing countries often see science as a "foreign culture" (Aikenhead and Jegede, 1999, p269). This is a challenge to science educators who embrace science for all: Laugksch (2000) argues that learners should develop the ability to understand the nature of scientific knowledge, to use science in solving problems and to appreciate the connection between science and technology and society. As such there is an emerging priority among science educators to develop culturally sensitive curricula and introduce teaching methods that will make science less of a foreign culture to students.

2.4.3.1. Cultural border crossing

Aikenhead (1996) proposed the theory of cultural border crossing as a metaphor to describe the difficulties students experienced as they struggled with the meaningful construction of western science concepts. By establishing the attributes of culture such as communication, attitudes, values and belief practices, he suggested that science should be regarded as a culture in its own right. Aikenhead chose Phelan *et al.*'s (1991) definition of culture because it involves knowledge, skills and values, which encompass anthropological and education characteristics associated with science education (in Aikenhead, 1996). From a cultural anthropology point of view, to learn science is to acquire the culture of science (Wolcott, 1991). When there is harmony between the culture of science and the students' view of the world, the process of enculturation can occur, but when the culture of science is at odds with the students' life-world, science instruction may disrupt the student's worldview which will then need to be reconstructed in a new way (Aikenhead, 1996.)

Within a group there are subgroups identified by race, language, ethnicity, gender, social class, occupation or religion. An individual may thus belong to several subgroups at the same time. Many combinations exist due to the associations that form naturally among people in society resulting in large numbers of subgroups. These subgroups, including families, peers, media, and the school, may influence students' understanding about science (Aikenhead, 1996).

As he considers students' experiences with science in terms of students crossing borders from the subcultures associated with peers, family, media and the school into the subcultures of science and school science, Aikenhead (1996) notes that science instruction is a cross-cultural event for most students. Both enculturation and assimilation require that the students are able to cross the cultural border into the subculture of science.

Aikenhead (1996) argues that non-western students who are successful in science demonstrate culture-related values of cooperation and attentiveness. The culture of western science may be foreign to students from both developed and developing countries, because non-western students have the traditional culture of their community and western students have their commonsense understanding of their physical world, i.e. their preconceptions that make sense within their life-world subcultures (Ibid.). Cobern (1996, p588) has referred to the isolation and segregation of school science within the minds of students as "cognitive apartheid". The fact that cognitive apartheid is practiced is supported by the finding that most students view traditional science content as having little or no relevance to their life-world subcultures (Aikenhead, 1996). The learning of science is thus influenced by the diverse subcultures within a student’s life-world, the student’s prior knowledge and the science-world of the teacher (Aikenhead 1996).

Constructivism highlights the role of prior knowledge, while the concept of cultural border crossing highlights the difficulties that are experienced in the context of a mismatch of worldviews. For African learners who hold a belief system shaped by both Christian and African beliefs, the presentation of facts in the science classroom, unmediated in terms of either of these belief systems, can result in cognitive and psychological conflict (Cameron, 2007). According to Aikenhead (1996, p4) “the view of learning science as culture acquisition affords an intuitive, holistic and rich appreciation of students’ experiences in a science classroom”.

Aikenhead (1996) together with others, including Cobern (1996), recommend that science teaching and learning be embedded in a social and technological background that has scope for students’ worldviews and practical experiences. Within science education, this involves the science-technology-society (STS) conceptualization, which is a movement to teaching science with a life-world background that helps students make sense out of their natural, technological and social worlds. STS provides multiple views of the natural world primarily from the students’ perspective, which is in contrast to the singular perspective of a scientist’s view of the natural world (Aikenhead, 1996). Jegede (1994) argues that this student-oriented multiple-vista conceptualization of science education harmonizes with a cross-cultural approach to science education. Aikenhead (1996) further argues that a cross-cultural STS science and technology curriculum can enrich student life-world subcultures by empowering them to draw on the subculture of science in appropriate situations, whether working situations or in understanding their own communities, which are increasingly influenced by western science and technology.

Aikenhead (1996, p15) draws on Costa‘s (1995) and Phelan *et al*’s (1991) categories of the way students cross borders to describe these transitions. These include 5 categories, i.e. potential scientists; other smart kids; “I don’t know” students; Outsiders and Inside Outsiders. These border crossings into the subculture of science are respectively described as “smooth, manageable, hazardous or virtually impossible” (Aikenhead, 1996, p18). Aikenhead (1996, p27) also introduced the idea of teachers acting as “culture brokers” or “tour guides” or as described by George (1999) “bridge builders”. This is where lecturers sensitively and with awareness of the need to facilitate epistemological access, recognize the impact of student worldviews on the learning of science.

2.4.3.2. Collateral learning

Jegede (1995) proposed the theory of collateral learning to explain the link between a learner’s context and prior knowledge, which is grounded in worldview, and their ability to integrate and appropriate new knowledge through holding different ideas and patterns of behaviour in different contexts. This ability to hold different, even conflicting, ideas has been called a “conceptual proliferation” (Aikenhead, 1997, p231), “Cognitive apartheid” (Cobern, 1996, p588) and “compartmentalization” (Waldrip and Taylor, 1999, p290). Jegede’s theory is widely used in South Africa because of its appealing framework in terms of examining learning in traditional and multicultural classrooms (Cameron, 2007). According to Aikenhead and Jegede (1999) when students experience cultural clashes, they either invent ways to avoid constructing scientific knowledge, or they store the constructed scientific knowledge away in their minds so that it does not interfere with their life-world experiences.

Jegede (1998) developed four levels of collateral learning: these were parallel, simultaneous, dependent and secured collateral learning. Secured collateral learning is when worldview knowledge is integrated with scientific knowledge. This means that any conflict in ideas has been resolved. Consciously compartmentalizing knowledge into various different realms is referred to as parallel collateral learning. Parallel collateral learning means that two conflicting schemas are held side by side in the long term memory and no progression is made towards resolution (Jegede 1995, 1998). In simultaneous collateral learning an idea in one domain of knowledge can facilitate the learning of a similar idea in another domain or background. In dependent collateral learning one idea from one worldview begins to challenge another idea from a different worldview, not necessarily permitting the student to modify an existing idea without radically restructuring the existing worldview. Jegede (1998) suggested that learners could move progressively through these levels from a situation of parallel collateral learning to a situation of integration where the knowledge was secured and where any conflicts were resolved.

In terms of science education, the question is whether collateral learning encompasses effective learning especially if it is maintained over a long time. According to Barbour (2000) compartmentalization prevents constructive interaction, so the question is whether science educators should be aiming for secured collateral learning as suggested by Jegede (1995), or whether they should promote compartmentalization in recognition of multiple ways of knowing.

The problem seems to be whether it is possible to integrate knowledge from two different worldviews. Cobern suggests that domination and replacement is the likely outcome of conflict between traditional and scientific explanations. In other words, he doesn't think that integration is a likely outcome. As mentioned earlier, Lewis and Aikenhead (2001) also question integration as a possibility because they claim that this integration could result in the traditional knowledge becoming subsumed by western modern science, thereby losing its identity.

The African ability to hold contradictory views and operate in two worlds in the long term is well documented (Mbiti, 2006). In certain cases community or religious constraints inevitably result in parallel collateral learning. For example when students learn about evolution, cognitive conflict may be dire and the only way students can cope is through parallel collateral learning (Cameron, 2007). In situations like this it would be unrealistic to strive for or demand integration but this does raise the question of meaningful learning. However, if the process of dependent collateral learning results in the tension being resolved in favour of western modern science, these ways of knowing may be lost. This loss of belief in traditional and religious ideas could potentially be very damaging socially and culturally (Aikenhead and Jegede, 1999).

It is possible to hold scientific and indigenous views of the world at the same time. In support of this, Ogawa (1995) proposed three types of science: Personal science, indigenous science and western modern science. By "multiscience teaching" Ogawa felt that western modern science could be enhanced by making students aware of personal and indigenous science in the classroom setting. Ogawa's proposal could be used to support the long term existence of parallel collateral learning, but it could also be used to dispute Jegede's preference for secured collateral learning as the most desired outcome for science teaching and learning, because education should not necessarily involve the loss of one way of knowing in favour of another. According to Jegede (1997) school science has been seen to promote a mythic text book science. For meaningful learning to occur science must be seen to be relevant and applicable to the every-day thoughts and actions of ordinary people, but western science may involve an imposition of one culture over another (Ibid.). In Africa the lack of relevance of western curricula to the everyday lives of African learners was usually not taken into consideration in the implementation of science curricula. Doughty (2005, p6) argues that "Africa's problems must be solved by Africans" and that the way to accomplish this is to reclaim, restore and revitalize indigenous knowledge. In South Africa there has been progress in the national education framework in terms of recognizing the importance of prior knowledge and the existence of other ways of knowing with regard to learning.

The problem of compartmentalization or integration remains unresolved. However, the theories of collateral learning and cultural border crossings provide a way of understanding how successful learning in science can be achieved.

2.4.4. Summary to section on the nature of tertiary science education

From the discussion of the literature current biotechnology curricula have been shown to be a product of globalization and of the enterprise of western modern science. Like other scientific disciplines, biotechnology is taught through curricula that have not been modified according to local contexts. In southern Africa, this necessitates the development of an appropriate curriculum by making it relevant and culturally sensitive and accessible to local students. Two worldview theories, border crossing and collateral learning, have been discussed to explain how students move between the world of science and their everyday worlds and how they deal with the conflicts between these two worlds.

2.5. Conclusion to Chapter 2

In the context of southern Africa, where there are many different 'ways of knowing', educators need to be aware of the need for providing epistemological access, especially in situations where cultural perspectives may be at odds with the epistemology of western science. The discussion of the nature of epistemology brings attention to the possible mismatches of a western curriculum based on western epistemologies being imposed in the context of African students, and draws attention to the influence of globalization on tertiary education. Globalization has placed a great demand on the use of scientific culture as the basis of quality living. In the context of southern Africa it has been shown that while Africans can effectively absorb and use scientific culture in everyday life, T&L can be supported by the development of a biotechnology curriculum that takes epistemology into consideration.

Chapter 3 – Positionality statement

3.1. Introduction

Research is unavoidably affected by issues of choice: choice of an instrument for data collection, the kind of data to be collected, the methodology that underpins these choices and the analysis that is applied to the data. These choices especially in education research, are inextricably linked to the research, and can be seen as limitations to the study. My personal biography, i.e. class, gender, race, culture and ethnic background, plays a role, as it is these traits that have influenced the analysis and informed the study. Positionality is important as it involves recognizing the influence of one's social, cultural, political and historical context on what one knows and how one knows it (Cameron, 2007). In this chapter I have therefore described my perspectives and I have tried to recognize my biases which will hopefully help in understanding how my background has both influenced my perceptions of and choices of the methodology and analysis of the study. I have set my positionality statement up according to the guidelines of Murillo (2012) i.e. in three sections relating to self; self in relation to others and from self to system.

3.2. Self

I am the eldest of three daughters born into a middle class white family in Kimberley in the Northern Cape in 1965. My father was an attorney (still practicing today) and my mother was a stay-at-home mom. I matriculated from Kimberley Girl's High in 1983. I studied at Stellenbosch University where I did a BSc., BSc. Hons and MSc. in plant genetics and breeding. I was always interested in agricultural biology as my Dad had a farm on the outskirts of Kimberley where we spent every Saturday of every weekend. We were in town on Sundays as we went to Sunday school at the Presbyterian Church and I played the piano for the little children's hymns in church.

I am not sure where, when or how I came across this adage "perseverance is the forerunner of success" but ever since I can remember this has been my personal motto. Our school motto was in the same vein i.e. "per labores ad honores". I have always believed in working hard to get anywhere in life. I was brought up in a home with good Christian values and practices and together with my husband we are doing the same for our two children.

I have always been interested in biology subjects and at Stellenbosch became more and more involved with genetics and in particular plant genetics, as it involved studying plants to improve them genetically through breeding for food production. The classical plant breeding methods evolved into the biotechnology methods we have today. My first PhD proposal entitled "The transfer of drought tolerance to tomato by bacterisation[5] and genetic engineering" (accepted Faculty of Science, WITS University, 1995) involved plant genetic engineering techniques to improve tomatoes for drought resistance. After starting my family I cancelled that PhD because my family became far more important to me than my career, and my plan was to eventually stop working and bring up my children. I was diagnosed with a chronic neurological disorder, multiple sclerosis (MS) at the end of 1999 and due to the expense of the medication I was forced to continue to work. The Medical Aid at that time only paid half the cost per month (the total cost for 4 intramuscular injections per month has always fluctuated between R8000-R9500 for the 13 years I have been on it, a monthly invoice today is exactly R9750).

Multiple sclerosis is a disorder in which T-cells infiltrate the central nervous system causing destruction of the myelin sheath that surrounds parts of many neurons. This can lead to muscle paralysis through a disruption in neuron function (Reece *et al*., 2011). In other words it is an autoimmune disease and results when the immune system is active against particular molecules of the body. Multiple sclerosis is treated by interferons which are examples of genetically engineered biopharmaceutical products and are hosted in *Escherichia coli* (*E.coli*) and mammalian cells. *E. coli* are bacteria and are called prokaryotes, meaning they are organisms without a nucleus, in contrast to eukaryotes (organisms whose cells all contain a nucleus). Bacteria have been widely used to produce therapeutic proteins such as the interferon I mention above. Prokaryotes synthesizing eukaryotic (humans, plant and animals)

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[5] Rhizobacteria are found in the rhizosphere (space around the root) of the plant. Some rhizobacteria have been shown to stimulate plant growth and are called plant growth promoting rhizobacteria (PGPR) (Davison, 1988). Bacterisation is a word my supervisor used for this process.

proteins can have disadvantages, for example prokaryotic cells cannot process and modify eukaryotic proteins and the proteins made do not always fold into the proper three-dimensional configuration needed in a eukaryote. To overcome these difficulties, eukaryotic hosts such as eukaryotic (plant and animal) cells in culture or transgenic animals are used. Goats, cows or sheep can make milk containing the desired therapeutic protein. In these cases the genes are inserted so that they are only expressed in the mammary glands of the animal. Yeast and insect cells can also be used. There are advantages for the animals, as transgenic animals with genes to protect them from pathogen infections can improve their quality of life as well. With my dependence on genetically modified interferon injections, I am already biased in my view of biotechnology, as it is probably what has given me the quality of life I have today.

3.3. Self in relation to others

I grew up in the Apartheid era. I had a very protected upbringing and I was quite oblivious to the system of racial segregation. As children, my sisters and I spent our Saturdays playing with the Tswana and Griqua children that lived on the farm and in the surrounding area of Hope Town and I never thought to question the differences in our lifestyles, it was just that they lived on the farm and went to the farm school, and we lived in town and went to school there. The end of apartheid resulted in the multi-racial democratic elections of 1994, and under the leadership of Nelson Mandela we became the 'rainbow nation' which recognized our many different cultures. It is the current students of these many cultures who are the participants of this study.

The Namibian university students are also multicultural, and were also subject to Apartheid from 1948 to their independence in 1990. Namibia was a German Colony before the League of Nations (an intergovernmental organization to instil peace after World War I) mandated the country to South Africa in 1948, when it became subject to our apartheid policy. The participants of this study from WITS and UNAM are therefore respectively 18 and 22 years post-apartheid, and they are of different races with different languages, religions, customs and traditions. However, all have proved through having been admitted to university, to have potential to be successful in tertiary education.

The people who have influenced me most along this journey of mine were lecturers at University, the one who will always standout said: “The price of sex is death”, this is because all animals that sexually reproduce through the process of meiosis die. Those that multiply through mitosis, i.e. bacteria, split to become two, never die. This sparked my interest in cell division. We as humans are around because of sexual reproduction which is possible because of the process of cell division, called meiosis, in which gametes are formed. Our genotype is a combination of 23 maternal and 23 paternal chromosomes, so that our genome consists of two chromosomes of each 23 types. Therefore, each gamete that we produce contains roughly 8.4 million (2^{23}) possible chromosome combinations, which means that in a fertilization event, a successful sperm represents 1 in 8 million different possibilities as does the egg involved, which means the zygote is a one in 70 trillion (2^{23} x 2^{23}) possible combinations of chromosomes (without even considering crossing over or genetic recombination), which makes each of us a 1 in 70 trillion chance of being who we are, i.e. exceptionally special. After all that energy to make that I in 70 trillion individual, one cannot just die, which is why I believe in eternal life which ties up with my Christian beliefs. On that note I need to reveal my take on evolution. I believe in adaptation to the environment and the change in body plan according to the change in the environment, especially because of sexual reproduction and the genetic variation that is generated from one generation to the next.

Evolution requires the fitness of the organism to survive. Fitness is the ability of organisms to survive and transmit genes to the next generation. Fitness has two principle components. It can be ascribed to reproduction (which determines the fertility and fecundity of the individual) vs. development and metabolism (which determines viability of the individual and it is dependent on the environment). Organisms adapt various sequences of meiosis which lead to different consequences which allow them to respond to different selection pressures. They are highly precise adaptations and keep the organisms fit and competitive in their respective environments (John, 1990). This is natural selection as proposed by Darwin when he noticed that individuals suited to a local environment leave the most offspring, thereby transmitting their genes and leading to the accumulation of genetic variations favoured by the environment (Campbell and Reece, 2008).

The sequencing of the human genome which is a result of many biotechnological techniques related to genetics, microbiology and biochemistry have very important applications; such as in product development, where genes are isolated and amplified, the gene product is mass produced and can then be used in the pharmaceutical industry, industrial chemicals and in agriculture; in predictive medicine and diagnostics, where disease-causing genes are identified; in population genetics where genomes are compared and specific gene variants from different people are compared to trace history; to identify gene function, which includes studying 'knock-out' mice and to identify therapeutic agents; and lastly the study of genome organization. Furthermore, this can help in evolutionary studies, so that genomes of different species can be compared.

With many scientific discoveries leading to change in medical history, the nature of scientific knowledge to me is to solve problems and cure illness, help the environment and learn about nature. As is described in the paragraphs above, my biotechnology experiences involve the improvement of my quality of life and my view of the potential of biotechnology, which includes its application for agricultural and product developments and the amount of information and data it produces through research associated with studies involving the Human Genome Project (HGP). All these reasons have culminated in my interest in teaching subjects relating to biotechnology, and together are the reasons I am involved in researching teaching and learning in biotechnology. These very reasons could also be seen as limitations to this study because of my bias to biotechnology and its use. It is for this reason that I chose phenomenography as the methodology for this research because as a second-order interpretive empirical research approach, the categories of description emerge from the data rather than the data being collected to confirm or contest preconceived ideas. I have then described how biotechnology appeared to the participants according to the way they answered my questions, which in itself is biased, as I made up the questions.

3.4. From self to system

What further emerges from this positionality statement for my study is that as an African myself, my belief system is shaped by my Christian beliefs and the socio-cultural background I described above, which forms my worldview. I have always been aware that we are all a 1 in 70 trillion chance of being, but at the same time I have had a western way of looking at things and I suppose I expected everyone else in this field to think in that way especially since they are studying science. My worldview obviously impacted this research, however as I have evolved with this research study, I have found that my horizons have widened as I have become more aware that we all have a different way of seeing things. I have been looking for that light bulb moment about the outcome of this study concerning biotechnology for months while writing up these chapters; and I finally realize that the constellation of light bulb moments that have presented themselves to me may have made me immune to seeing how amazing each one is separately, however, at the same time my broadened outlook has embraced this constellation of light bulb moments and I am overwhelmed by what I find. I was also overwhelmed by the diversity, richness and honesty of the answers I received from all the participants involved in this study. I attended the "Data-mining revolution" conference in Stellenbosch (10-12 September 2012), all based on biotechnological concepts and I found that even the people on the cutting edge of research in Genetics and Bioinformatics, and highly respected in their fields for their knowledge, seemed overwhelmed. This once again reiterates the tsunami of information that is coming from biotechnology techniques and the tsunami of ways we can use the information.

I have been teaching genetics and other biotechnology related subjects at WITS since January 1995, i.e. 18 years. Using a constructivist approach, I have always done my best to make use of innovative teaching, learning and assessment strategies that address student problems. Constructivism is an accepted theory of learning (Piaget 1964, 2003) and it means that new knowledge is constructed on what one already knows. Knowledge can thus be thought of as a product of worldview. Worldview is then shaped by the socio-cultural environment of the human experience. As a lifelong learner, I have a socio-constructivist approach. This approach was articulated in the work of Vygotsky (1978), who focused on the roles that society plays in the development of an individual in the "zone of proximal development" (Vygotsky, 1978), which is the difference between what you learn on your own and what you have potential to learn when assisted.

Thus, this research has investigated whether and how the practices and ideas of biotechnology may be in disaccord with the cultural beliefs and understandings of the participants within the educational theory of socio-cultural constructivism. Once again, the limitations here could be due to my bias as the researcher because this represents a new field of research, and it is important in highlighting where potential conflicts may arise. Cognitive and epistemological conflicts may create barriers to learning, if they are not addressed. These barriers to learning may even lead to student drop-out. My aim is thus to enhance the learning environment to support educational transmission and transformation so that students become independent problem-solving professionals who have a qualification to make a difference in our environment.

I have always recognized the importance of prior knowledge and through SANTED and this research study I have had the opportunity to face the multicultural image of science and to recognize that there are other ways of knowing with regard to learning. Furthermore, by recognizing different worldviews through incorporating indigenous knowledge with biotechnology knowledge could be a way forward, especially when considering indigenous knowledge as a way of living sustainably.

Despite the limitations mentioned in this positionality statement every effort has been made to be objective and to maximize the trustworthiness of the study through questionnaires, interviews and focus groups which were transcribed and analysed using the methodology of phenomenography.

In conclusion, as southern Africans, our historical landscape and cultural heritage are so unique and this qualitative study is a way of preserving the freshness, honesty and naivety of the responses so it can be seen as a type of monument of scientific value to our heritage especially since our diversity of knowledge is in danger of extinction if we refrain from acknowledging it over that which comes from the West.

Chapter 4 – Research Methodology

4.1. Introduction

As outlined in the previous chapters, the intention of this research study was to investigate potential worldview concerns associated with biotechnology and consequently whether the curriculum could be shaped to respond to meet the need to provide epistemological access. The purpose of this chapter is to outline and explain the methodology that was used in this investigation.

To begin this chapter, the first section provides a background to qualitative research procedures. The second section describes the use of case studies which provide the opportunity to focus on a particular context for a particular purpose. In this case study, phenomenography was chosen as the most suitable methodological approach, because it allows for the emergence of different understandings of a phenomenon. Phenomenography enables the investigation of how people experience, conceptualize, perceive and understand a particular phenomenon (Akerlind, 2005; Booth, 1997; Marton, 1986). In this case study, the phenomenon to be considered is how students and lecturers in the research sample understood and experienced biotechnology.

The next section describes the participants making up the research sample and explains the instruments used for the data collection i.e. student questionnaires; semi-structured interviews and focus groups. Examples of these instruments are provided in Appendices A, B and C. This is followed by a discussion of the data analysis process and a consideration of the criteria for assessing the trustworthiness of the research. The last section is a conclusion to the chapter.

4.2. Background on qualitative procedures

The search for 'understanding' or 'knowing' is the key focus of any scientific research, and it aims to add to the body of knowledge or theory in its field. Qualitative research procedures are used in educational research where the broad focus is to provide 'insights and contributions for improving practice', and to enlighten decision making and policy development (Plomp, 2008).

Qualitative research as noted by Merriam *et al.* (2003) is flexible because the research process is continually unfolding as the study seeks to understand a dynamic and continuously evolving process. This is because qualitative research is concerned with process and with understanding the process (Merriam *et al*., 2003; Merriam, 1998). In this study which was to investigate the question of epistemological access, the process involved accessing and describing the different worldview responses to the phenomenon of biotechnology. According to Opie (2004) it is impossible to engage in educational research and not be concerned with epistemology and with epistemological questions and issues. Creswell (2009) states that the process of qualitative research involves emerging questions and procedures, data typically collected in the participants' setting, the data analysis, inductively building from particulars to general themes, and the researcher making interpretations of the meaning of the data. Creswell (2009) further argues that qualitative research is undertaken as a means to explore and investigate the meaning individuals or groups ascribe to a social or human problem. It is also a form of inquiry that supports a way of looking at research that honours an inductive style. Inductive research begins with the collection of data, which become the observations the researcher interprets (Hayes, 2000). An inductive style involves a focus on meaning, and the importance of interpreting the complexity of a situation (Creswell, 2009). Throughout this study the focus of the inquiry process was on understanding the meaning that the participants held about the phenomenon biotechnology.

The research questions posed required an in-depth study of teacher and learner epistemologies of biotechnology. Consequently phenomenography was used as the research approach and applied to a case study involving biotechnology curriculum development in two SADC universities, i.e. WITS and UNAM.

Worldview theory has been used as the theoretical framework (Cobern, 1996) for this study. The data was collected at the two SADC universities with the intention of gaining an in-depth understanding of lecturers' and students' views and responses to biotechnology. As outlined in Chapter 1 the study was stimulated by the opportunity to develop a curriculum that could be regarded as an "African" product for use by the two participating SADC institutions.

Usually in a case study, a global issue is explored through a specific case (Merriam, 1998). Here, the global issue is that biotechnology is becoming a major research thrust. The specific case under investigation is the biotechnology curriculum which is required to support capacity development in southern Africa. According to Opie (2004), the focus of a case study is a real situation, with real people in an environment which is familiar to the researcher. In this case study, the SANTED project involved my teaching at both WITS and UNAM meaning that the people and the context were familiar to me.

In this case study, phenomenography was used to look into the different ways people at WITS and UNAM experienced the phenomenon of biotechnology. Phenomenographic analysis investigates human experience of a particular phenomenon (Akerlind, 2005; Booth, 1997) and the object of phenomenographic research is variation in human meaning, understanding, conception and their experience of the particular phenomenon (Marton, 1981; 1986). This method seemed suited to meeting the needs of this study in that it investigates collective meaning, i.e. the qualitatively different ways people experience and or think about biotechnology.

From the literature, it appears that phenomenography is emerging in educational research as an increasingly useful approach to qualitative research especially in the natural sciences, geographical sciences, life sciences and in health care, particularly in nursing (Barnard *et al.,* 1999; Bowden, 2005). It is a unique research approach which allows for the emergence of understanding of how a phenomenon is experienced and understood.

In a case study and in phenomenography the data collection must be systematically undertaken. Both methodologies make use of the same data collection instruments. The result of a case study, however, is not to implement any changes as a result of its findings (Opie, 2004). Rather the findings from a case study and from the 'outcome space' (results) of phenomenography could be used to influence practice, or result in recommendations for change.

4.3. The case study

The aim of a case study is to describe a certain feature of social behaviour or activity in a particular setting and the factors influencing this situation (Creswell, 2009). According to Flyuvbjerg (2011) (in Denzin and Lincoln, 2011, p301) the choice of the unit of study is the key factor in defining a study as a case study. This means it is the choice of what is to be studied that is important in the case study. A case study can involve a single person, a group of people within a setting, a class, a department within a school or a whole school for example (Opie, 2004). According to Opie (2004) a case study can be viewed as an in-depth study of interactions of a single instance in an enclosed system. Through a case study, the interactions of events, human relationships and other factors are studied in a unique location (Opie, 2004).

A variety of data collection procedures are used to collect detailed information in a case study (Creswell, 2009). The procedures used to collect data in this case study were semi-structured interviews, questionnaires and focus groups. More details of these instruments are discussed in the sections below. A case study takes place for a defined period of time (Leedy and Ormrod, 2005) in this case the research took place from 2009 to 2012.

According to Opie (2004), in a case study, being able to generalize the findings is not as important as being able to consider how the findings relate to similar settings. “Detail, richness, completeness and within-case variance” are all factors that add to the depth of a case study (Flyuvbjerg in Denzin and Lincoln, 2011, p314). Thus, in this case study the experience of the phenomenon, biotechnology, was studied in relation to biotechnology capacity development at two tertiary institutions in the SADC region.

4.4. Phenomenography

Phenomenography, as a research method, was developed by a team of researchers at the University of Gothenburg, Sweden, who were interested in researching the experience of learning in a qualitative way (Marton and Saljo, 1976). One of the most significant contributions made by the Swedish phenomenographers has been the concept of different approaches to learning and that a distinction can be made between deep and surface approaches to learning. (Ibid.). Phenomenography has a strong pedagogical agenda (Prosser and Trigwell, 1999) and highlights awareness of teaching and learning that focuses on student understanding (Booth, 1997).

Phenomenography has continued to evolve as a qualitative research approach since its origin in Sweden. Qualitative research methodologies highlight scientific, philosophical or linguistic 'turns'[6]. The 'turn' of phenomenography is scientific (Barnard *et al*., 1999). Marton (1986) referred to it as an empirical research tradition used in educational research to answer questions about thinking and learning. Ornek (2008) writes about it as the empirical study of the qualitatively different ways in which people think of various aspects of phenomena in the world around them i.e. how they experience, conceptualize, realize and understand various aspects of phenomena. While Sonneman (1954) first used the term 'phenomenography', it was from the 1970s that phenomenography developed into a distinctive qualitative approach to understanding not only learning, but a broad range of phenomena (Barnard *et al*., 1999). Marton and Booth (1997, p125) describe phenomenographic research as "awareness of ways of experiencing a particular phenomenon". This methodology fits well with the intention of this research, which was to investigate the qualitatively different ways lecturers and students at WITS and UNAM experienced, conceptualized and understood biotechnology. In the literature on phenomenographic research the relation between a person and the phenomenon is described as either 'conceptions' (Harris, 2011; Svensson, 1997) or 'ways of experiencing a phenomenon' (Marton and Booth , 1997).

Phenomenography takes a second order perspective because the researcher studies the phenomenon through how it is experienced by others e.g. the lecturers and students, as opposed to studying the phenomenon directly (Reed and Case, 2004). Phenomenographic research is not about studying a given phenomenon. Rather it is the experience of the phenomenon that is the subject of the research (Ornek, 2008). People live "in an experienced world" (Prosser and Trigwell, 1999, p59) i.e. how the world appears to them shapes how they

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[6] Turn means the search for the knowledge basis of support in answering questions about a research method (Svensson, 1984).

act in the world and how they react in a particular situation and at a particular time. This means that there are different ways a phenomenon can be experienced i.e. that there is variation. Because there are various ways people can experience a phenomenon, it is important that only essential qualitative differences that characterize the variation should be focused on. Thus, according to Marton and Booth (1997) it follows that to gain insight into the variation in the ways people experience the phenomenon, the researcher should attempt to break down individual experiences so that what is crucially different about the collective ways in which the phenomenon is experienced becomes evident. The phenomenographic focus is thus on the collective, not the individual experience. By focussing on the collective, the phenomenography process aims to make up a logical structure (Akerlind, 2005). The rationale behind this approach is that the research outcomes need to be amenable to practical implementation for pedagogical effectiveness; so they need to be as parsimonious as possible. The empirically interpreted different meanings include structural relationships linking the different ways of experiencing the phenomenon. The relationships are the structure of the 'outcome space'. The outcome space is the phenomenographic term for 'results' and it constitutes a logically inclusive structure relating the different meanings and ways of experiencing a phenomenon (Akerlind, 2005).

According to Marton and Booth (1997) phenomenography supports a non-dualistic ontology, which relates to how the one world that exists is experienced in different ways by different people. What this refers to is how the world is experienced, i.e. that it "is not constructed by the learner, nor is it imposed upon [the learner], it is constituted as an internal relation between them." (Ibid., p13) i.e. the subject and the object are not independent of each other.

Svensson (1984) indicated that general ontological and epistemological assumptions are considered in the phenomenographic approach as they are represented in the conceptions (the ways of experiencing) of the phenomena. The ontological assumption holds that a person acts in the world on the basis of the way they experience it i.e. the way in which they are aware of that world (Marton and Booth, 1997). The hypothesis of structural relationships between different ways of experiencing a phenomenon is one of the epistemological assumptions underlying the approach (Akerlind, 2005). In other words, a person cannot know anything about the world independently of their experience of it. Thus a person's knowledge consists of their conceptions of the phenomenon, as they have experienced it.

The descriptions and observations of the ways people experience the phenomenon are examined to discover what is qualitatively different about them so that distinct categories can be identified. Each category is labelled and these are referred to as 'categories of description' (Akerlind, 2005; Marton, 1981). The ways these categories are similar and different and how they correlate illustrates what is most important about how the sample group/participants experience or perceive the phenomenon in question. The structure of similarities, differences and associations is characteristic of the sample group and is called the 'structure of awareness' and together with the categories of description, constitutes the 'outcome space' (Marton and Booth, 1997). The outcome space constitutes a logically inclusive structure relating the different meanings and ways of experiencing a phenomenon (Akerlind, 2005).

Conceptions are central to describing knowledge in phenomenography (Marton, 1986). When Marton (1988) used the term 'conceptions' of phenomena in the world around us, he was referring to 'the different understandings' of such phenomena. A person's conception of a phenomenon is determined by the way in which he/she becomes aware of that phenomenon. According to Marton *et al.* (1993) there are a number of possible components of a conception. These components include referential (what is the experience?) and structural (how is it experienced?) aspects. Referential aspects refer to the global meaning attributed to the phenomenon, i.e. the referential aspect involves the assignment of meaning to the phenomenon as revealed by the structural distinctions which identify it in the person's perception (Marton and Booth, 1997). The structural aspects refer to how the phenomenon and its different parts are related to each other i.e. the structural aspect involves recognition of the structural elements of a phenomenon which enable it to stand out from everything else around it (Marton and Booth, 1997). Furthermore, the way the structural aspect of a phenomenon is experienced is twofold: Marton (1986) and Booth (1997) go on to say that there is an "external horizon" which relates to the background features in which the phenomenon is found and which is called the 'thematic field'. The "internal horizon" or foreground is the way in which the phenomenon and its parts are understood and are related to one another, and is called the 'theme' (Booth, 1997, p153, Figure3).

How a person comes to know something is understood in terms of awareness, and Marton and Booth (1997) describe the 'structure of awareness', as a conceptual framework, that provides an explanation of what it takes for a person to be aware of a phenomenon. These two aspects of awareness are the structural and referential aspects of awareness as discussed above. The relationship of these two aspects in terms of the experience of the phenomenon is shown in Figure 4.1:

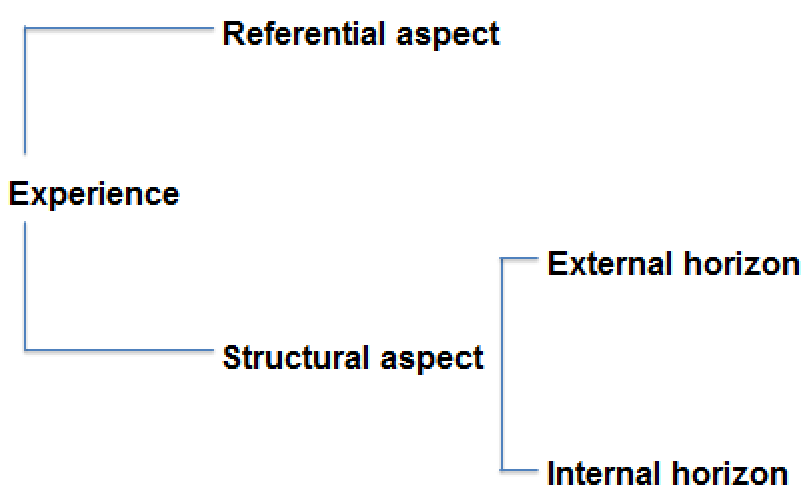

Figure 4.1: The generic structure of awareness (Adapted from Marton and Booth, 1997, p88)

Akerlind (2005, p331) describes an individual's experience of a phenomenon as "context sensitive". This means that phenomena may be perceived differently by different people and differently by the same people under different circumstances. Our conceptions result from the interrelationship between our beliefs, education, culture, history, expectations and experience. Thus our worldview influences our conceptions. Because this interrelationship influences our thinking and the way we in which we respond to the world around us and because our conceptions can differ or be similar, this relational basis of knowledge results in variation and is key to phenomenography (Barnard *et al.,* 1999). This methodology provides the opportunity to analyse the qualitatively different ways in which people experience and understand aspects of a phenomenon, and as discussed in chapters 1 and 2, this is dependent on cultural and environmental backgrounds. Both influence how people experience various aspects of phenomena in the world around them. Thus their worldview will influence how they perceive and experience the phenomenon.

In order to keep the focus on the collective experience of the phenomenon it is important for the researcher to keep an open mind during the analysis and upon reflection to constantly adjust their thinking. This involves reflection on all the responses to one question at a time to understand the collective meaning. According to Marton *et al.* (1993) an individual rarely expresses a conception in its entirety. It is therefore necessary to consider the entire transcript for context, meaning and perspective. To this end all transcribed questionnaires and interviews in this study were colour coded to keep the information from each transcript aligned (See Appendix C, each student is numbered and has a coloured font to help highlight the responses of the same student throughout). Phenomenographic research is an iterative process and the researcher should look at data from different perspectives at different times, also bearing in mind that an individual's experience of a phenomenon is context sensitive (Akerlind, 2005, p322). The need to consider the entire context, meaning and perspective highlights an interrelationship between both subject and object.

4.4.1. Categories of Description and the Outcome space

In phenomenographic research the description of the conceptions represent the main outcome, and they are presented in "categories of description". These conceptions need to be differentiated from each other by having distinctive features (Akerlind, 2005). The term "categories of description" is used to describe experiences of the phenomenon because there are different meanings and ways of experiencing it (Akerlind, 2005). The term categories of description distinguish the hypothetical experience from the empirically interpreted collective experience. The theory of phenomenography is that the different ways of experiencing i.e. the categories of description, will be logically related through the common phenomenon being experienced (Ibid.).

By focussing on the collective meaning, phenomenography aims to make up a logical structure relating the different meanings. The categories of description established by the researcher to represent different ways of experiencing a phenomenon are thus seen as forming the structured set, called the outcome space (Akerlind, 2005), where the categories of description are hierarchically related. As far as information relating to the phenomenon is concerned, Marton and Säljö (1976a) explain that "hierarchically related" means that level A implies level B, and level B implies levels C and D etc. With respect to the hypothetically complete different ways of experiencing a phenomenon, the outcome space is inevitably partial (Akerlind, 2005); however, this can still make a substantial contribution to the understanding of the experience of the phenomenon in question.

The categories of description also clarify the relations between different ways of experiencing the phenomenon (Akerlind, 2005, p322). By focusing on the 'what' and 'how' aspects of the phenomenon (i.e. what was the experience in this case, of biotechnology and how biotechnology was experienced) the referential and structural components of the outcome space emerge. This involves focusing on similarities and differences within and between categories.

The outcome space provides a way of looking at collective human experience of the phenomenon holistically. The categories of description should represent the full range of possible ways of experiencing the phenomenon in the population represented by the sample group. In the phenomenographic outcome space, each category should have something distinctive concerning the understanding/experiencing of the phenomenon (Akerlind, 2005), and the categories should be structurally inclusive. Akerlind recommends that there should only be a few categories with variation in experiences (Ibid. p323).

Martin and Booth (1997) advise that the main idea for the development of the outcome space is that the different categories of description of the ways of experiencing a phenomenon are assumed to be related to one another and should have hierarchically inclusive relationships. By representing a structured outcome space one provides a way of looking at human experience of the phenomenon with a focus on the collective. In this way, according to Marton and Booth, all possible ways of experiencing the phenomenon by the particular sample group, at that particular time, are represented.

The categories of description should be relational, experiential, content oriented and descriptive (Marton, 1988). "Relational" concerns the subject-object relation making up the conception; the "experiential", concerns the experience of the participants in the study; "content oriented", is concerned with the meaning of the phenomenon being studied; and "descriptive" concerns the qualitative account of the phenomenon. Each category of description is related in the form of the outcome space and forms part of a larger whole (Ibid.).

In this study, the categories of description represented the collective understanding of biotechnology. The referential aspect of the outcome space was "what" the experience of biotechnology was. The structural aspect of the outcome space was "how" biotechnology was experienced. The external horizon in this case, was tertiary education teaching and learning, and the internal horizon was biotechnology experience in tertiary education teaching and learning. The "what" and the "how" described by Marton and Booth, (1997) are the two elements of each category i.e. what the participant experienced in biotechnology and how they experienced it. Phenomenography enabled this research study to explore the range of meaning within the sample group i.e. the different conceptions of biotechnology were represented in categories of description which highlighted the different ways in which the phenomenon "biotechnology" was experienced by the lecturers and students at WITS and UNAM.

4.5. Participants

The participants were made up of two groups: lecturers and students. The lecturer sample included 13 lecturers (7 from UNAM and 6 from WITS) involved in teaching the biotechnology courses at the two institutions. The student sample comprised students from the 3rd year undergraduate Bachelor of Science (BSc) in the School of Molecular and Cell Biology at WITS; and in the Department of Biological Sciences at UNAM. The final student sample was made up of 4 different groups of third year students (2009-2012) and a small honours group (2010, who had not answered the questionnaires in their third year) involved in biotechnology courses, according to year of study. In all there were 115 student participants and 9 focus groups (See Tables 4.1 and 4.2 in the following sections).

In phenomenography the analysis is at the collective level. Consequently issues of gender, race, or socio-economic conditions of the participants (Reed and Case, 2004) are of little consideration. However, because the theoretical framework of this study is worldview consideration it was worth at least noting the diversity of the participants in terms of gender, race, language and secondary education experience. While the students are taught in English at both WITS and UNAM, the lecturers and the students have a variety of different home languages i.e. Afrikaans, Damara, Damara-nama, Oshiwambo, Oshindonga, Otjiherero, Rukavanga, Rukwangali, Setskiana, Shona (Zimbabwean language) and Lunda (Zambian language) at UNAM; and English, Tshivenda, Afrikaans, Sepedi, German, Zulu, Sesotho, Xhosa, and French at WITS. This range of languages highlights the cultural diversity of both the lecturers and the students in this case study.

The 2009 UNAM cohort of 20 third year undergraduate students were the first to be introduced to the new biotechnology courses. These courses were discussed and planned at the SANTED curriculum development workshops held at WITS in 2006 and 2007. There are two third year biotechnology courses in this new curriculum, namely Recombinant DNA Technology and Biotechnology.

In order to gather the necessary data, semi-structured interviews, student questionnaires and focus groups were held, all with the intention of assessing participants teaching and learning experiences of biotechnology.

To gather data at UNAM, questionnaires were completed by the students involved in these courses in 2009 and 2011 in the two weeks of cross-border teaching that was done there. At the same time the UNAM lecturers were interviewed. At WITS, interviews, questionnaires and focus groups were carried out throughout 2010, 2011 and 2012.

4.5.1. Brief description of the courses the participating students were involved in

The descriptions of the courses the students in this study were doing at the time are described below. These descriptions are what appeared in the faculty handbooks verbatim i.e. the Faculty of Science, Biological Sciences at UNAM (2009) and the Faculty of Science, Biological Sciences, at WITS (2009). These are descriptions of what is covered in each course to provide the students with the information. The descriptions are not in the same tone as they were all written separately by the lecturers involved in teaching them.

UNAM courses

SMBL3731 Recombinant DNA technology

Recombinant DNA techniques were developed through discoveries in molecular biology and molecular biological processes. The principles and applications of the following techniques are discussed: nucleic acid extraction, gel electrophoresis, restriction and other modifying enzymes, cloning vehicles and the cloning process, polymerase chain reaction, transformation, gene libraries, identifying recombinants, sequencing and characterizing genes.

SMBL3712 Biotechnology

This course is aimed at giving students a sound basic knowledge and skills in biotechnology related topics: Introduction to biotechnology: definitions, scope of biotechnology, principles and techniques in genetics, biochemistry and microbiology, issues around GMOs. Genomics: Definitions, concepts of gene expression and analysis, techniques –genomic libraries and analysis, southern blots, applications. Proteomics: definitions, concepts of protein expression and analysis, techniques-SDS PAGE gels, western blots, applications. Transcriptomics: definitions, concepts of gene regulation in prokaryotes and eukaryotes and analysis, techniques –cDNA libraries and analysis, Northern blots, applications. Metabalomics: definitions, concepts of metabolism and analysis, primary and secondary metabolites, Techniques – metabolic pathways and analysis, site directed mutagenesis, applications. Introduction into Bioinformatics: definitions, principles of bioinformatics, Techniques –databases and database searches, software usage, applications.

WITS courses

MCBG3014 Chromosomes and Gene Maps

This course looks into various aspects of human molecular genetics coupled with the information and techniques from the Human Genome Project. The former includes organization of the human genome, the structure and function of chromosomes and chromosome abnormalities. We look into genetic recombination, its applications in mapping genes to chromosomes and the construction of genetics linkage maps in humans and identification of genes for disease. We study genes in pedigrees and populations, including how genetic and epigenetic factors contribute to the phenotypes of complex diseases in humans. Information from the Human Genome Project includes the different biotechnological techniques used. Through these techniques we will discover how these studies have led to an exciting era in human genetics research. The second part of the course correlates cellular events, especially those of the chromosome, with genetic phenomena, by following the sequences and consequences of meiosis in various different organisms. The practical component includes the visualization of human chromosomes and linkage mapping in the fruit fly *Drosophila*.

MCBG3022 Biotechnology of Fungi III

This course provides an overview of the use of fungi in the biotechnology of the food industry; the production of biochemicals; in medical biotechnology; agricultural biotechnology; environmental biotechnology; and bioremediation. Detailed aspects cover the use of yeasts and fungal cell wall –degrading enzymes in the food industry; the use of white rot fungi in the pulp and paper industry; fungi and the biodegradation of industrial and mining wastes.

MCBG3018 Advanced Virology III

This topic will cover principles of virus-host interactions and pathology with respect to human and animal viruses, with specific emphasis on the host immune response. Included in this will be the strategies employed by the different viruses to subvert the host immune response. We will also address virus evolution in some detail and in that context, try and understand the emergence of new viral diseases such as HIV/AIDS and SARS.

MCBG 3025 Plant Biotechnology and Genetic Engineering III

Plant genetic engineering involves the horizontal transfer of genes between different species. Genetic engineering and biotechnology involves the identification of useful proteins that will enhance the phenotypic attributes of crop plants such as: agronomic performance, food quality, invertebrate pest resistance, environmental stress resistance, and microbial pathogen resistance. Plant biotechnology involves the isolation and cloning of genes encoding proteins that will have a beneficial impact on crop production or that will enhance the quality of crop products. The course will focus on the recent advances that have been made in plant genetic engineering and plant molecular biology. The theoretical background for the understanding of genetic engineering procedures will be covered in detail. Practical laboratories will involve in vitro plant propagation and regeneration and molecular biological techniques and procedures for the genetic transformation of plants.

Topics that were covered in two-weeks of cross-border teaching at UNAM

Plant genomes - organization and expression of genes; plant tissue culture and techniques for plant transformation and vectors for plant transformation; i.e. essentially the requirements for Plant Genetic Engineering: Delivery of foreign DNA to a plant; Regeneration of transformed tissue into mature transformed plants; Expression of transferred genes; Stable inheritance of transferred genes; Safety and environmental considerations. On my second visit we also added a brief outline of the Human Genome Project and the techniques involved.

4.6. Data collection

The type of data collected in a case study and in phenomenographic research can take various forms. During this research study, three different data collection methods were used: semi-structured interviews, questionnaires and focus group discussions (Denzin and Lincoln, 1994). The data was collected over a period of 4 years at both WITS and UNAM. A series of questions for semi-structured interviews and questionnaires were developed in advance, aimed at evoking a comprehensive account of the participants' experience of the phenomenon.

The approach used to develop the questions that were asked in the interviews, questionnaires and focus groups was to align the questions with the research questions (See Appendix A). The interview questions and questionnaires were thus divided into three sections. The first section of questions concentrated on general aspects such as participant background, teaching and learning practices and the learning of concepts in science and biotechnology. The second section included questions concerning biotechnology and biotechnology applications and practices and the way people conceived various aspects of biotechnology. The third section was concerned with various aspects of the biotechnology curriculum, what content was included, and the way it was taught. The WITS ethics policy was followed in relation to the creation of the instruments and ethics clearance was obtained (See Appendix B for the questions as they were sent in with the application for ethical clearance. See Appendix E for a copy of the ethics clearance certificate: Protocol number H100 202).

The questionnaires, interviews and focus group interviews were voluntary (see Appendix B for the invitation to participate and the information sheet). All recordings of interviews and focus group discussions were transcribed verbatim. The transcripts then provided the data to be used for analysis.

A pilot study was done (Opie, 2005) to determine whether the data instruments were suitable for the purpose of the study and so that I could gain some experience in doing interviews. It was also done to find the most suitable way to perform the data collection. In a qualitative study, pilot testing of the instruments can be considered an informal way of establishing whether the instruments need to be modified to ensure quality data gathering (Opie, 2005). The questions were not modified, because based on the pilot study, the answers to the questions seemed to give a rich source of data with varied information. The time taken to fill out the questionnaires was about 30 minutes, which was adequate to get sufficient information and not too long to result in negative reaction. The participants involved in the pilot study were representative of the main sample and because of this, their data was included in the data collected (i.e. questionnaires and 3 interviews from 2009 and 2010).

4.6.1. Questionnaires

Questionnaires were administered to the following student participants: 3rd year UNAM undergraduate students (2009 and 2011); 3rd year WITS undergraduate students (2010 and 2011); and WITS Honours students (2010) for the Plant Genetic Engineering and Breeding topic. As can be seen from Table 4.1, the student response to the questionnaires at WITS when they were handed out and asked to return them at a later date was very poor. Consequently in 2011, the time when students had to wait for incubations in practical laboratory periods was used as an opportunity for completing questionnaires. Giving them out then and asking for them to be returned before students left led to a much better rate of return. The exercise was voluntary and there were students who did not participate. The number of questionnaires that were handed out compared to the number of answered questionnaires that were returned is shown in Table 4.1. The table shows the institution, the year the questionnaires were handed out, how many students were supposedly enrolled for the course, together with the number of questionnaires that were returned to me and the female to male breakdown in returned questionnaires. Although the difference between female and male responses is not a focus in this study, it is interesting to note that as far as students are concerned, far more females than males were doing the biotechnology courses, and as far as academic staff were concerned, far more males than females teach the biotechnology courses. This held true at both WITS and UNAM during the time of the study.

The questionnaires provided a rich source of data, but in order to validate the data collected and to deepen the trustworthiness of the research, other data collection methods were also employed, i.e. semi-structured interviews and focus groups.

Table 4.1: Summary of the numbers of questionnaires that were handed out and collected at the two SADC institutions.

University	**Year**	**Course**	**Total number of students enrolled**	**Total number of completed questionnaires**	**♀:♂ ratio**
UNAM	2009	Biotechnology III	22	15	12:3
	2011	Biotechnology III	72*	40	29:11
WITS	2010	Biotechnology of Fungi III	60	17	15:2
	2010	Honours Plant Genetic Engineering	8	6	4:2
	2011	Advanced Virology III	38	37	30:7
Total	3 years		200	115	90 : 25

*As justification for a good questionnaire return rate at UNAM, it should be noted that according to the HOD at UNAM although there were 72 students enrolled for the 3rd year courses, the venues assigned to the courses could only seat 48 students.

4.6.2. Semi-structured interviews

Semi-structured interviews are usually used in phenomenographic research (Green, 2005). Lecturers teaching in the biotechnology curriculum at WITS and UNAM were invited to participate in this study. Thirteen agreed to be interviewed, with a semi-structured interview format being used, in which the interviewee was asked open-ended questions so that the individual's experience of the phenomenon could be highlighted and described. (See Appendix A and B for the interview questions).

The interview questions were sent to the participants before the interview, which increased interest in the topic, and seemed to help the participants feel more comfortable about giving up their time to do the interview. It was also found to encourage a relaxed atmosphere. This is in accordance with Barnard *et al.* (1999) who suggest creating a relaxed interview style when doing a phenomenographic interview. One participant actually answered all the questions in writing before the interview.

Permission was requested to audio tape the interviews. Notes were also taken. Transcriptions were always done on the same day as the interview so that it was still fresh in my mind. Participants were asked if they would like to check the transcription. The transcribed interviews were sent to participants for checking if requested.

List of semi-structured interviews:

UNAM

2009: 1 male junior lecturer

2011: 6 males ranging from junior lecturer to Full Professor and 2 Heads of Department

WITS

2010: 5 males ranging from lecturer to full professor

2012: 1 female lecturer and one male associate professor

4.6.3. Focus group discussions

Merton et al.(1956)(in Denzin and Lincoln, 1994) coined the term "focus group" to apply to a situation in which the interviewer asks group members very specific questions about a topic after considerable research has already been completed. Krueger (1988, p18) defines a focus group as a "carefully planned discussion designed to obtain perceptions in a defined area of interest in a permissive, non-threatening environment" (as cited in Lewis, 1995). In order to probe the views and ideas shared by respondents in the questionnaires, I decided to use focus groups to probe some of the themes that came out of the questionnaires.

The focus group interview is essentially a qualitative data gathering technique where the interviewer directs the interaction and inquiry in either a very structured or unstructured manner, depending on the interview's purpose (Denzin & Lincoln, 1994). According to Denzin and Lincoln (1994) the more common uses of focus groups include: obtaining general background information about a topic of interest; stimulating new ideas and creative concepts; generating impressions of products, programs, services, institutions, or other objects of interest; learning how respondents talk about the phenomenon of interest which may facilitate quantitative research tools; and interpreting previously obtained qualitative results (Stewart and Shamdasani, 1990).

Generally focus groups consist of between 6-12 people, and it has been suggested that the size of the group should not be so large as to be unwieldy or to preclude adequate participation by most members, nor should it be so small that it fails to provide substantially greater coverage than that of a questionnaire or an interview with one participant (Merton *et al.*, 1990). When participants have a great deal to share about the topic or have had intense or lengthy experiences with the topic of discussion, smaller groups (4-6 people) are preferable (Kreuger, 1988). The number of focus groups can vary according to the number of different subgroups required. Morgan (1988) (as cited in Lewis, 1995) believes that one group is never enough as you may be observing the dynamics of that group and little else.

Convenience sampling, according to Opie (2004) involves choosing the nearest individuals. Convenience groups of WITS third year students (meaning the students involved in a biotechnology course I was teaching at the time) were invited to take part in focus group discussions, which were to unpack themes, particularly relating to biotechnology products and GMOS in everyday life that arose in the 2009, 2010 and 2011 questionnaires.

Focus group interviews were conducted with 6 – 8 interviewees in each group. They involved particular semi-structured and open-ended questions intended to elicit views and opinions from the participants, typically 4 to 6 interview questions were asked. Table 4.2 is a summary of the focus groups that were held. The table shows the year the focus group was carried out, the course the students were doing, the total number of students enrolled for the course and the total number of students who took part per focus group together with the female to male ratio in the group.

Table 4.2: Summary of the focus groups that were held.

University	Year	Course	Focus group number	Total number of students enrolled	Number of students in focus group	♀:♂ ratio
WITS	2011	Chromosomes and Gene Maps III	1	25 students (16 females, 7 males).	6	6 : 0
			2		8	5 : 3
			3		9	6 : 3
	2012	Chromosomes and Gene Maps III	1	48 (35 females, 12 males)	9	5 : 4
			2		8	5 : 3
			3		8	7 : 1
			4		7	5 : 2
			5		8	6 : 2
			6		7	4 : 3
Total		9 focus groups		73	70	49 : 21

A comfortable atmosphere was necessary that was conducive to the sharing of opinions and open communication. The focus group participants chose their own groups, basically following their practical laboratory groups. At third year level, they are not expected to sit in alphabetical order in practical laboratories anymore. However, the remnants of alphabetical order is apparent which originates from first year practical laboratories where they have to sit in alphabetical order and they then become friends so they keep more or less the same order, which is only really interrupted by friendships that were formed outside the classroom. The key element in focus groups is the involvement of people where their disclosures are encouraged in a nurturing environment. The focus groups were held in a spacious laboratory, during class time when students had incubation breaks in the practical laboratory. In this way the focus group discussions did not impose on their private time. Permission to record the discussions was obtained from students. These discussions were transcribed, and the transcriptions served as the data for analysis.

Focus groups were not held at UNAM when I returned for the week of cross border teaching and learning in 2011 because of logistics and time constraints. Questionnaires only were used as we only had a week of lectures together and I did not want to lose class and teaching time. Also the UNAM students were very forthcoming with their answers to the questionnaires and as can be seen from Table 4.1, most of the students who attended my lectures for each of the cross-border teaching weeks returned completed questionnaires.

The focus groups served the purpose of validation through triangulation, especially since they allowed me to probe the opinions raised by the students in the questionnaires. They also stimulated more in depth discussions and the collection of rich descriptive data. According to Stewart and Shamdasani (1990), this is due to the fact that, during focus group discussions participants can stimulate the ideas of others. Focus group discussions tap into human tendencies where attitudes and perceptions are developed through the interaction with other people and individuals opinions may shift due to the influence of other comments or they may be held with certainty (Lewis, 1995).

<u>The questions that were asked in the focus groups:</u>

1. What does biotechnology mean to you?

2. How acceptable to you is what you are learning in terms of your community beliefs? What are those beliefs?

3. Is there anything in your biotechnology classes that you would hesitate to tell people in your community about?

4. What are your views on GM foods? Are you happy to use GM foods in your family meals? When you do grocery shopping do you consciously check to see if the products have GM status?

5. Do any biotechnology practices make you uncomfortable?

6. What societal and economic problems in southern Africa could be addressed by biotechnology? /What biotechnology subjects do you think are important for students to learn with regard to your interests and /or the economy in your country?

4.7. Data analysis

Phenomenographic analysis which is an “interpretive-analytic process” begins with the differentiation and organization of data (Svensson 1984; 1997). Answered questionnaires, interview and focus group transcripts provided data which was analysed for meanings that were compared and grouped into categories of description which characterized experience of biotechnology. Interviewees may not always have described all their conceptions of biotechnology, but they did express conceptions concerning the phenomenon within the reality of their world at the time of the interview.

There is no precise procedure for a phenomenographic analysis in the literature, and according to Akerlind (2005) there is variation in practice. The main objective, however, is to discover the least set of categories from the data that describes the essential differences in the ways the sample group experience, perceive or understand the phenomenon that is the focus of the study. The transcriptions from the questionnaires, interviews and focus groups provided the data to be used for analysis. This gave a total number of 135 transcripts to be analysed (Student questionnaires were 106 pages. A sample with a couple of transcribed answered questionnaires is included in Appendix C for validation reasons). The transcripts were subjected to an interactive process of manual coding to identify the conceptions of biotechnology (Richardson, 1999).

Phenomenographic analysis starts with a search for meaning or variation in meaning, followed by a search for structural relationships between meanings (Akerlind, 2005, p325). The analysis thus began with a search for meaning, and variation in meaning, across all the transcripts while trying to maintain a focus on the collective experience.

By first reading through all the data, a general sense of the information was gained and the overall meaning was reflected upon. Creswell (2009) describes the “emergence” of sets of categories or meanings from the data. This required keeping an open mind (Akerlind, 2005) and re-reading of the data several times to get to a point where individual conceptions were supportive of a category of description that emerged (Akerlind, 2005). This required me to be as open as possible to different meanings and interpretations, for example students often said similar things but their underlying meaning was different and the whole transcript needed to be seen as a set of interrelated meanings, which can be understood in relation to each other (Akerlind, 2005). The set of categories or meanings that resulted from the analysis ‘emerged’ from the data through rereading individual transcripts and defining similarities and differences among the transcripts and the categories that had emerged. This was an iterative, heuristic and time-consuming process and involved the sorting and resorting of the data to find the conceptions which would then form the categories of description (Akerlind, 2005).

A common element in phenomenographic studies is the sense of saturation or theoretical exhaustion (Akerlind 2005) that grows in the latter stages of the analysis as the divergences are explored and the categories are refined. Once the categories have been decided upon they are labelled and constitute the categories of description that define the different ways in which the sample group relates to the phenomenon. The labels are important and must convey as precisely as possible the essence of what distinguishes one category from another. In phenomenography, it is not the number of participants that is important but the wealth of information that is generated (Creswell, 2009).

Text and segment sentences or paragraphs were labelled as conceptions, according to the perceived substance of the information or underlying meaning. Throughout the process a record of my thoughts was kept in the margins. When this process of coding had been completed for all participants, it was followed by the categorization process. This involved finding the most descriptive wording according to what categories the expressions of experience (conceptions) emerged into (Tables of the groupings are included in Appendix F for each sample group). In other words the expressions of experience (conceptions) were grouped to form the categories. The expressions of experience (conceptions) were grouped to reduce the total list of categories to get the most parsimonious categories.

The final stage in this phenomenographic study was to establish the structure of awareness that characterized the sample group (Akerlind, 2005; Bowden, 2005; Marton and Booth, 1997). This involved an analysis of the categories of description that focused on the dimensions of variation that distinguish categories from one another i.e. what was similar, what was different and what was critical in going from one category to another. In such an analysis, attention is given to both the structural and referential dimensions of awareness described earlier in this chapter. The outcome space was then created using the structure of awareness and the categories of description that had emerged. The categories of description were represented in the outcome space in a hierarchical manner from the rudimentary level to the complex level, for example, from a less sophisticated awareness to a more sophisticated awareness. This analysis and interpretation thereof is presented and described in the following chapter.

4.8. Trustworthiness

An important aspect of any qualitative research study is that the findings are trustworthy. Strategies to ensure the trustworthiness of the data and results were derived from the model of Lincoln and Guba (1985). They involve 'credibility', 'transferability', 'dependability' and 'confirmability'. More detail on each of these is described in the paragraphs below. All these form an appropriate basis for assessing the 'trustworthiness' of interpretive research and for judging whether the outcome of phenomenographic research can be taken seriously (Collier-Reed *et al*., 2009). According to Badenhorst (2008) these traditional criteria for judging qualitative research are applied in research designs through triangulation. Campbell and Fiske (1959) introduced the concept "triangulation" as a synonym for convergent validation, meaning that information from different sources can be used to substantiate and illuminate the research problem and therefore help to limit any biases, whether personal or methodological. Denzin (1978) identified 4 types of triangulation i.e. data triangulation, method triangulation; investigator triangulation, and theoretical triangulation. Data triangulation was applied in this research study.

Data triangulation was accomplished through the use of the three different data collection methods described. This was useful in finding support for the concepts and themes that were identified and to ensure that data saturation was achieved. In terms of the trustworthiness of the research process, ethical clearance was obtained unconditionally (Protocol number H100 202, Appendix E) and questionnaires, interviews and focus group interviews were voluntary. As mentioned earlier, all recordings of interviews and focus group discussions were transcribed verbatim as were the questionnaires which contained the hand-written answers of the students. Interviewee participants were also offered the opportunity to check their interview transcript.

With regard to credibility, which relates to how valid findings are, the concern is that analysis should be based on clearly articulated theories, responsiveness to research questions and the use of appropriate methodological procedures for ensuring quality and consistency in data interpretations. A review of the literature also ensures credibility of findings, because the literature is used to frame the problem and inform the study. The literature presented in the study then also becomes the basis for comparing and contrasting the finding of the research study.

With regard to confirmability the issue is how reflective the findings are of all involved parties. The principle source of the credibility and confirmability evidence in this study was that interviews and focus groups were recorded with the permission of the participants. This was to check that the students' and lecturers' responses to each statement were correctly transcribed and to verify interpretations of the responses.

With regard to transferability the issue has to do with how relevant the findings are to other settings and with regard to dependability the question is how consistent and reproducible the results are (Lincoln and Guba, 1985). In terms of transferability, as the outcome of this study applies to WITS and UNAM, they are representative of southern Africa's multicultural communities and the findings should be relevant for other universities in the SADC region. In terms of both the transferability and dependability of the research a detailed description of the research methodology was done. The use of various data collection methods and specifically, consistency in the application of data capturing methods, such as the use of the same questions for each participant interviewed and the same questions in all questionnaires, further contributed to the dependability of the study. Creating meaningful results involves transferability which also has to do with 'validity', and whether or not research findings seem accurate or reasonable. In phenomenographic research, for validity the researcher asks the question of how well the research outcomes "correspond to human experience of the phenomenon" (Uljens, 1996 in Akerlind, 2005, p330).

According to Marton (1988) it is not necessary to replicate the outcome space, for the purpose of ensuring its reliability. However, Herbert and Pierce (2008) point out that the categories of description should be recognized by another researcher. Akerlind (2005, p332) refers to this as a "coder reliability check", which involves two researchers independently coding a sample of interview transcripts and comparing categorizations. In order to meet this requirement, a session was organized with two colleagues to validate the categories of description that emerged from the data analysis. This was done by these colleagues randomly choosing two questions from the questionnaires. These were question 14 (What does the word biotechnology mean to you?) and question 23 (What are your views on genetically modified (GM) foods?). These colleagues then independently coded the forty student responses to each question into a category. The categories that emerged for each of them were then compared, and they were compared to my categories. The result was that the categories these colleagues assigned to the student answers were almost fully in accord with my categories. Where there was any difference the difference was discussed and agreement was obtained, but this affected very few of the answers, confirming the categories of description that were created.

In phenomenography, in the transcription and data analysis phases, dependability can be checked using team-based research, which involves two or more researchers involved in the development of the categories of description (Collier-Reed *et al.*, 2009). However, as this is a

PhD study, a single- researcher mode was necessary, and the dependability of the data analysis then rests on the credibility of the methodology used (Ibid.).

Finally, while this research study was in progress, some of the work was published, having gone through a blind peer review process: one publication was in The International Journal of Learning (2011) and two publications were in the proceedings of the International Organization of Science and Technology in Education (2008 and 2010) symposia (Copies of the abstracts of each paper are included in Appendix D).

4.9. Conclusion to Chapter 4

This chapter has presented the background to the research methodology selected for this study. It has outlined the details of the methodology of choice, i.e. a case study in which a phenomenographic approach was used; the composition of the research sample; the data collection methods and data analysis methods. From the analysis the subjective knowledge of the participants, with its meaning and understanding was categorized into six levels of description which reflected the various views of biotechnology.

Initially, the data had been pooled so that it could be viewed as a collective, and, although at the outset there was great variation in conceptions of biotechnology, on being subjected to the iterative process of the methodology which led to the categories of description, the similarities were what emerged. The categories of description of biotechnology were then hierarchically related to find new insights and to find how they related to each other through the outcome space. In the outcome space each category revealed something distinctive about a way of experiencing or understanding biotechnology.

The following chapter, chapter 5 presents the analysis of the data and the outcome space in which two categories of description emerged, which were logically and inclusively related.

Chapter 5: Data analysis, results and interpretation

5.1. Introduction

The purpose of this study was to explore student and lecturer conceptions of biotechnology as a scientific discipline and to consider the existence and nature of worldview concerns in the context of biotechnology education. The rationale behind the phenomenographic approach that was used for this investigation is that the research outcomes need to be amenable to practical implementation for pedagogical effectiveness. This means they need to be as parsimonious as possible (Akerlind, 2005).

Due to the pedagogical interest of the study i.e. to provide insight to improve students' learning and understanding of biotechnology by addressing their personal epistemologies in addition to science and techno-epistemologies (described in the literature review in chapter 2), this study focused particularly on student and lecturer experiences of biotechnology with regard to teaching and learning.

This chapter begins by explaining how the data were analysed and how the categories of description emerged. An overview of the findings is then presented, which is followed by a discussion on the qualitatively different categories of description that resulted from the phenomenographic analysis. This leads to a presentation of the findings as the "outcome space", in which the emergent categories of description are presented. The variations in meaning and ways of experiencing biotechnology can be seen in these "categories of description", which are set out initially in Tables 5.1 and 5.2. Tables 5.3 and 5.4 represent a refinement of the initial categories of description. In exploring the range of meanings within the sample group, each category in the outcome space has exposed something distinctive about a way of understanding and experiencing the phenomenon, i.e. biotechnology. Through the analysis, initially six categories of description emerged. However, these categories of description could be merged to produce the most parsimoniously distinct categories: here the six initial categories were reduced to two qualitatively different categories which encapsulated the full range of ways that biotechnology was experienced collectively by the population represented by the sample group. The final section includes a conclusion to the chapter.

5.2. Data analysis

The general methodology for analysing the data in a phenomenographic study was described in Sections 4.4 and 4.7. As indicated, the object of a phenomenographic research study is variation in human meaning, understanding, conception and experience of a phenomenon. Harris (2011) describes the unit of analysis as 'conceptions' and Marton and Booth (1997) describe it as 'ways of experiencing a phenomenon'. In this research study, the objective of the analysis was to discover the most parsimonious set of categories that would describe the essential ways the sample group experienced the phenomenon. As mentioned in the previous chapter, there is no precise procedure for a phenomenographic analysis. According to Akerlind (2005) there is variation in the practice and Harris (2011, p117) argues that this variation "highlights the need for researchers to justify why they are using a particular framework and how they conceptualise it, showing their analytical processes". In response to Harris' injunction, a detailed description of the analysis of the data for this research study follows in the next section.

The data analysis began with my immersion in the transcriptions of the interviews, questionnaires and focus group responses. The data was read and examined repeatedly, and accompanied by making lists and notes of interesting features and recurring themes. In so doing a deep familiarity with the data began to grow. Subsequently, the most appropriate way to make the data manageable was by dividing the transcripts into meaningful sections, then coding these so that similar meaning could be collected together, compared and analysed. By analysing such coded sections, the categories of description began to emerge indicating the qualitative variation of student and lecturer experiences of biotechnology. The text i.e. sentences or short paragraphs, were coded as conceptions, according to the perceived substance of the information or underlying meaning. At the same time, my thoughts were recorded in the margins. When all the transcriptions had been engaged with in this way, a list of all conceptions was made with similar topics being clustered together. This was followed by the categorization process. This stage in the analysis involved merging collections of similarly coded conceptions into categories that were qualitatively similar. This involved tabularizing the conceptions (Tables of the groupings are included in Appendix F for each sample group) and then checking the columns in the tables to re-evaluate distinctive collections. The conceptions that were qualitatively similar were then sorted into categories. This process involved establishing the most appropriate descriptions according to the categories that emerged. In other words the conceptions were grouped to form the categories. The conceptions were also grouped to reduce the total list of categories to distil the essence that distinguished each category from the next. In this way a set of categories was finally identified by grouping similar coded conceptions into themes which became the categories of description.

This method of analysis was applied to the data from each of the instruments used, and for the different sample groups i.e. lecturers at WITS and UNAM and students at WITS and UNAM. Initially the data from each sample group was analysed separately, to make it more manageable, but because the outcome of this research was not about comparing the separate groups, and because saturation in the conceptions was reached, the data was finally combined to represent the collective experience of the phenomenon biotechnology. By focussing on the collective, the categories, as discussed, all emerged from both the lecturer and student conceptions and they were then analysed together as one data set, representing the sample population of the case study.

Much iteration of the processes just described was required to eventually produce what was considered a meaningful and consolidated basis for distinguishing the variations that were conceived as the categories of description.

Once the categories of description had emerged, the coding of all transcripts was reviewed, and because Marton (1988) indicates it is not necessary to replicate the outcome space, for the purpose of ensuring its reliability, the categories of description were confirmed by another two colleagues in a ’coder reliability check’ (Akerlind, 2005, p332). In this process, two colleagues independently coded a sample of transcripts to validate the categories of description that emerged from the data analysis. The need for this was discussed in more detail in Section 4.8 in the previous chapter.

The categories of description were then each analysed and are described in detail in Section 5.5, where quotes from the transcripts are used to illustrate and support argument for the categories chosen. Descriptions of the distinguishing features of each category are also presented.

As this is the first time this type of research has been applied in biotechnology education in southern Africa, there were no validated questionnaires in the literature to draw on. The quality of the questions constructed can thus be seen as a limitation to the study, but a pilot study, as discussed in the previous chapter, was used to increase the validity of the questions that were used. The pilot study was especially aimed at testing the questions to check for unforeseen difficulties (Novak and Gowin, 1984) and to add to the trustworthiness of the study. Quaye (2007, p8) argues that "(r)esearch, ultimately, is a messy endeavour with competing values, needs, and beliefs. The challenge is to find one's voice, develop it, and creatively use it. Responding to this challenge is a step towards extending what counts as research". As a trained scientist, I subscribe to the necessity to ensure the validity and reliability of the research process. As a biotechnologist it is even more critical as the products of biotechnology can mean life or death, for example in the production of medication. Comments by qualitative researchers such as Quaye are challenging in their own right, yet comforting in their recognition that because research in education inevitably deals with human beings and is within the affective domain, it cannot be approached in the traditional ways practiced by scientists. Nonetheless, the use of a validated methodology, and the application of rigorous criteria for integrity and trustworthiness of qualitative research make the findings of this research study trustworthy.

Furthermore, due to the diversity of the participants in terms of their multicultural backgrounds and different home languages it was sometimes difficult to decide on how to assign a particular comment to a category. This was noticed in the student questionnaires in particular. The impact of language i.e. the use of particular words by students (especially where English is their second or third language), could affect how I interpreted the responses. This is where the focus groups served to enrich and confirm the data collected from the questionnaires, because perceived ambiguities could be probed and discussed to help my understanding of their views.

The data collected was to provide insight into participants' worldviews and personal epistemologies with reference to biotechnology. The answers given in the interviews, questionnaires and focus groups were very informative, open and honest, reflecting the level of trust that had developed between the participants and me as the researcher.

5.3. Conventions for presenting quotes from the transcribed data

In this and the following chapter, quotes from the transcriptions are used to support the interpretation and discussion of the findings. All quotes are presented verbatim as they were written or said by participants, and are presented according to the normal conventions. The referencing format used to identify each quote was as follows: U or W for UNAM or WITS; L, S, H or FG for lecturer, student, honours student or focus group; a number according to the number I gave the transcript, and year the data was collected in brackets. Thus, for example [UL1(2010)] refers to UNAM, lecturer number 1, interviewed in 2010.

5.4. General overview of the findings

The tables presented in Appendix F provide a summary of the analysis of the transcripts of interviews with the lecturers interviewed at WITS, lecturers interviewed at UNAM; student questionnaires from UNAM; student questionnaires from WITS, and finally focus groups from WITS. Each table presents the most common conceptions that emerged from the data, i.e. the ideas that came up most were listed in the first column. As columns 2-7 developed they became the categories of description, such that when a conception in column 1 fell into the category of description it was marked as appropriate with an X in columns 2, 3, 4, 5, 6 or 7. It can be seen that a single conception could be assigned to different categories at the same time. The ways the conceptions are similar or different, and how they correlate and in some cases apply to different categories of description at the same time, highlights how the sample group experienced or perceived the phenomenon in question differently due to their different worldview. As discussed in the previous chapter, Marton *et al.* (1993) point out that an individual rarely expresses a conception in its entirety. Furthermore, Akerlind (2005) states that an individual's experience of a phenomenon is "context sensitive". Both Marton *et al.* and Akerlind indicate that people relate to the phenomenon being perceived differently, and that they may perceive it differently under different circumstances. Thus conceptions can fall within the different categories, which is how the categories that emerge are connected. How they become hierarchically connected through the structure of the outcome space will be addressed in Section 5.5.

The categories of description that emerged through using this phenomenographic approach to understand the participants' experience of biotechnology as a scientific discipline were:

1. Biotechnology is associated with building knowledge,

2. Biotechnology has powerful application potential,

3. Biotechnology leads to skills development,

4. Biotechnology evokes ethical and moral considerations,

5. Biotechnology is perceived as provoking ambivalence,

6. Biotechnology is perceived as having risk and harm potential.

Each of these categories of description is described in the following section, so that the distinction between each can be clarified. Finally, the structure of awareness that characterizes the target population is established in the outcome space in Section 5.6.

5.5. Categories of description

In this section, each category of description is discussed by describing it in detail, along with an explanation of its distinguishing characteristics.

5.5.1. Category I: Biotechnology is associated with building knowledge

In this category the focus of attention is on the variation in how biotechnology is associated with building knowledge. Knowledge is described as "fact or condition of knowing something with familiarity gained through experience or association" (http://www.merriam-webster.com/dictionary/knowledge) or as "Human faculty resulting from interpreted information…" (http://www.businessdictionary.com/definition/knowledge.html). Using these two definitions of knowledge, it can be said that knowledge is mostly information that has been interpreted through experience or association. As such, in this study, it was found that there were four specific but interconnected aspects regarding building knowledge in terms of the experience of teaching and learning in biotechnology: These included aspects relating to **building new knowledge**; aspects relating to **building on prior knowledge**; **the social aspects of knowledge associated with biotechnology;** and **cultural aspects of knowledge associated with biotechnology**. These distinctions may appear to be a matter of semantics; however, with regard to this study they are distinct characteristics that distinguish building knowledge through the experience of biotechnology as a category of description, and they are the four subcategories discussed below.

Aspects relating to building new knowledge

When relating their experience of biotechnology most students found the knowledge presented was new to them. On the one hand, the new knowledge was exciting and amazing to different students, as in the following quote: "…..The things I learn in these classes are so amazing I can hardly believe them. I would usually go like "Really? that's unbelievably unbelievable" [US31(2011)] and on the other hand, it was also described as difficult, because it was so new: "…It seems difficult but its (sic) because most of the information is new to me"[US1(2009)]. When asked what the participants found most difficult in studying biotechnology subjects, the most common response was the "foreignness of ideas". For most participants, the knowledge associated with biotechnology was a 'whole new world' with foreign ideas. Concepts were foreign because in many cases they involved ideas about invisible matter, such as molecules like DNA or microorganisms.

An example of this "difficult" new knowledge involves bacteria being used to transfer genes across species to make genetically modified organisms. An example of this is bacteria with vectors such as *Agrobacterium*[7] (often called "Nature's little engineer") which contains the Ti plasmid that naturally transfers DNA into plant genomes. However, although this was seen as "foreign" knowledge it was also seen as knowledge that is interesting: "Interesting how Agrobacteria can be manipulated to make our lives easier – relating to plants. Transgenic plants

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[7] *Agrobacterium tumefaciens* is the name most often used in texts and publications but the official scientific name is *Rhizobium radiobacter* (http://pir.uniprot.org/taxonomy/358. Access date: 17 September 2012*)*

are increasing daily" [US15(2009)]. Here what has emerged is that although the knowledge may be new, it was found to be interesting and that it could be useful.

When students were asked whether what they were learning in biotechnology was 'believable', a participant responded: "Hard to believe concepts first time hear about them (sic) – becomes clear and believable with understanding" [WS10(2010)]. This response illustrates learning that addresses ideas at the level of epistemology: students begin to shift in how they view the world as a result of what they are learning in the biotechnology course. Such learning is new and may shift participants' epistemological beliefs, which have been influenced by their worldview and social and cultural background.

Participants were clearly interested in the knowledge associated with biotechnology and they were keen to learn and acquire this new knowledge. This knowledge was associated with a sense of empowerment: "Knowledge is power and biotechnology is one of them (sic)" [US6(2009)]. Building knowledge through the experience of biotechnology was perceived as useful and empowering, because it could provide good career opportunities. One of the lecturers responded to the question of "(w)hat is it about biotechnology that specifically led you to want to teach it?" by saying: "Transfer of knowledge, skills and understanding that would equip students with regard to career opportunities. The skills involved in biotechnology lead to better opportunities than those for conventional botany…." [WL3(2010)]. In response to the question "(w)hat does biotechnology mean to you?" a student said: "…[biotechnology is] a good initiative. At least now we know we'll get jobs that are important, very important" [US12(2009)]. From the above it is evident that biotechnology as a broad field of new knowledge was valued by the participants because it opens up opportunities.

<u>Aspects relating to building on prior knowledge</u>

When asked about their experience of learning biotechnology, a number of students immediately related it to their prior knowledge or experience. When asked to describe their response to learning about biotechnology, answers were along the line of: "- Bread baking, when I saw the dough rising after yeast was added and kept in sunlight for some time"[US9(2009)]; "There are some biotechnological application in homes (everyday life) e.g. in brewing traditional food and baking”[US2(20110], and in the subtext of the following quote: “I haven’t heard much about the topic before coming to university, but I have been interested in how we can use common household things like crops and animals to develop our livelihood”[US8(2009)].

In hearing about the principles of biotechnology, the student participants thus seemed to be aware of common household tasks that incorporated elements of biotechnology. This new awareness could be what excited them about the value of biotechnology without them actually realizing they were assimilating the new knowledge with their prior knowledge and that this could lead to further empowerment, such as in their communities and with regard to environmental considerations. Assimilation, according to Piaget (1964, 2003) describes a process through which we perceive and adapt to new information and experiences, and then incorporate them into our existing ideas. The following response to the question “what motivated you to learn biotechnology?” supports how what they know in relation to the use of biotechnology knowledge can help with development and practices in the community: “The high levels of cholera in my home village was a source of great motivation for me to enter the biotechnology field. Thought it would be better for my community if one of us knew the steps to purify water” [WS6(2010)].

The successful building of new knowledge on prior knowledge has been theorized as constructivism, which was discussed in the literature review in Chapter 2. The recognition of the importance of biotechnology in daily life led to recognition of the new knowledge having value, especially with regard to career opportunities and opportunities for improving daily life in communities.

Social aspects of knowledge associated with biotechnology

There was a desire amongst participants to develop the technology and investigate its use in their own regions more deeply and in so doing become an interconnected SADC: “I think it would be better if countries combine ideas, because we all have similar situations /problems and we also have indigenous methods that we can share… ”[WS20(2011)]; similarly in a response to what biotechnology means, one student wrote: “Biotechnology helps me to understand the future and how we can fight drought, femine (sic) and mulnutrition (sic) as well as diseases prevailing in Africa as well as help in developing our country (sic)" [US25(2011)]. Biotechnology courses are designed to help students build biotechnology knowledge for solving agricultural and environmental problems. This was acknowledged by the student who said: "It [biotechnology] allows one to look at problems from other angles and new solutions to problems, which are more effective, environmentally sound and economically favourable can be found" [WS9(2010)].

When asked if there was anything in biotechnology classes that participants would hesitate to tell people in their communities about, it was generally felt that people in the community did not understand biotechnology practices "…People against [biotechnology] have no background information and they don't know what is going on" [US27(2011)]. It appears that participants feel that by building biotechnology knowledge and with growing understanding of biotechnology knowledge there was hope that biotechnology practices could be accepted in communities.

Cultural aspects of knowledge associated with biotechnology.

The theory and practice of biotechnology knowledge may be offensive and raise sensitivities to different religious or cultural beliefs. The different social practices and worldviews of the participants and the link between participants' epistemological beliefs and the way they responded to biotechnology knowledge was evident when there was hesitation to discuss biotechnology issues. Students indicated they would be hesitant to share what they had learned with the religious sector or older generation in their communities: "I wouldn't share certain ideas with religious people as this can be offensive to them e.g. evolution. I would share info that they can relate to, and understand easily" [WS24(2011)]. A lack of knowledge about these concepts makes it difficult for the layman to understand and it sometimes conjures up fear of the unknown, even images of strange things being produced: "Some and many things I learned are unacceptable in my belief e.g. cloning organism is one of the things that my community was against due to belief that unimaginary things will be produced (cloned) ……." [US37(2011)]. In contrast to this there were participants who felt that biotechnology knowledge enhanced understanding in the area of religion, as revealed by the following quotes: "The intricacy is beautiful it is a confirmation of God" [WFG1(2011)] and "I am religious but still believe God created everything and when you study science you can really see what He was thinking" [US6(2011)].

5.5.2. Category 2: Biotechnology has powerful application potential

One of the lecturers summarized the scope of biotechnology as: "… to Heal, Fuel and Feed the world. […] The healing is the medical side, the fuelling is the industrial side: commodities, chemicals and big bioreactors, and feeding is the agricultural side" [WL4(2010)], thus giving a broad overview of the application potential of biotechnology. Quotes such as "(b)iotech can make life easier" [US21(2011)] and biotechnology can "(c)hange Africa from poverty" [US6(2009)] illustrate the application potential that participants saw in relation to the knowledge of biotechnology.

In this category of the experience of biotechnology, the focus was on experiencing biotechnology in terms of its potential for a particular purpose. The variation of meaning included in this idea was that application potential had both **intrinsic value** and **extrinsic value**. The intrinsic value referred to applications benefitting the individual, while in the case of the extrinsic value, the benefit was for humankind and the environment.

<u>Intrinsic value of the application of biotechnology</u>

The internal and intrinsic value of biotechnology related to participants' feeling that biotechnology applications enhanced their employability and opened up amazing career opportunities. For example, one participant said: "It [biotechnology] is so broad as well, and one can make a career out of it, and branch out into any field" [WFG3(2012)]. Biotechnology was also seen as offering the opportunity to become famous for discovering something: "I have always wanted to be known and remembered for doing something that will have greater impact on the whole globe, and I figured out biotechnology is the way through (sic)" [US40(2011)], or finding a cure for disease: "I chose this field for medical research for treatments and cures" [WFG3(2012)]. There was also the purely intrinsic value of wanting to be rich. When asked why the interest in biotechnology a participant responded: "Making money!" [WL2(2010)].

Extrinsic value of the application of biotechnology

In contrast to the intrinsic value of the applications associated with biotechnology, biotechnology was also valued for its potential to solve problems for humankind and the environment: "Discovering how biotechnology can be applied to gear towards a sustainable environment and economy changed my hopeless attitude towards a biology/science related career. Through biotechnology we can fight poverty" [WH5(2010)] and "To me it means the use of micro-organisms in the production of various products (biodiesel, beer, paper, bioplastics) to reduce the harmful elements usually used or produced in the production of these products" [WS8(2010)]. Biotechnology was also seen to enable understanding and help to answer questions in the community highlighting its application in everyday life: "… the work done relates to things in the everyday life. It can help produce more food and improve the economy" [WS19(2011)].

The following quote illustrates the extrinsic value of the application of biotechnology, where a participant explained why biotechnology was acceptable: "Acceptable to me because can help develop our communities and country" [US25(2011)]. Furthermore, according to participants the applications of biomimicry and bioprocessing could help mankind and the environment and have led to participant interest in biotechnology: "Watching a video about biomimicry" [WS3(20110)], made a student interested in studying biotechnology. An interest in biomimicry has also led to the development of ethno-medicines. According to a lecture participant "It [biotechnology] means a lot to me, my current interest is now ethno-medicines which is something I developed out of my work on HIV/AIDS over the years… I went into ethno-medicines so that we can try to develop cheaper drugs from our indigenous plants" [UL 4(2011)].

As can be seen from the above discussion, the participants' level of acceptance of biotechnology practices used for healing (medical side), fuelling (industrial side) and feeding (agricultural side) depended largely on the application of biotechnology as having an intrinsic and an extrinsic value.

5.5.3. Category 3: Biotechnology leads to skills development

In this category the focus is on how the experience of biotechnology leads to the development of skills. It was found that there were three qualitatively different types of skills associated with biotechnology and that these could lead to empowering the participants in their life-worlds and science-worlds: these include **analytical skills** (analysing experimental results); **practical skills** (hands-on everyday skills, practical laboratory skills such as DNA extractions and cloning experiments, and breeding skills for improving agriculture) and **problem-solving skills**.

Analytical skills

"Analytical skill is the ability to visualize, articulate, and solve both complex and uncomplicated problems and concepts and make decisions based on available information. These skills demonstrate the ability to apply logical thinking when gathering and analysing information, designing and testing solutions to problems, and formulating plans" (http://www.linkedin.com/skills/skill/Analytical_Skills). According to participants biotechnology subjects provided them with analytical skills. One participant said: "A BSc with biotechnology subjects, especially genetics and biochem (sic), you learn a lot of skills. Due to these skills one could go into B Comm. Accounting which is analytical and we as BSc students think analytically about problems" [WFG1(2011)] and according to others: "Very knowledgeable and challenging. Allows one to think critically and analytically. Improves way of looking at things" and "Great skills learned because wrote loads of scientific reports and read and analysed scientific papers" [WFG1(2011)].

Practical skills

According to participants the skills they attain through biotechnology can prepare them better for life, as put by one participant: “BSc has helped me a lot opened up my thinking - better prepared for life” [WFG1(2011)]. The skills can be applied in any community and like applications they have an intrinsic value, where participants use them for their own development. The skills also have an extrinsic value where they are beneficial to communities, as these skills can provide a platform for economic growth.

Often biotechnology involves working with highly sophisticated equipment such as gel electrophoresis and bioreactors, which requires knowledge and skill. The practical skills associated with biotechnology are also related to the theory, as illustrated by the following quote: “When we were working with algae genetic engineering transferring required genes. This was the work of a biotechnologist as theory and practical skills went hand in hand” [WS25(2011)].

Lecturer participants wanted to teach biotechnology because of the transfer of knowledge, skills and understanding that would adequately equip students to pursue career opportunities in biotechnology. Some of the lecturers interviewed travelled to South Africa from Namibia, Zimbabwe and Austria to pursue studies in Biotechnology; and from different African countries to Namibia in pursuit of knowledge, skill and application. Practical skills in biotechnology are generic, and involve skills in biochemistry, genetics and microbiology laboratory research.

Problem-solving skills

The transfer of biotechnology knowledge and understanding helps participants with problem-solving skills, which can add to their employability or to their ability to be independent and to do entrepreneurial research and/or business: “Helps one to think in a problem solving manner” [WS3(2010)] and furthermore according to a lecturer interviewed: “South Africa was always a [seen as a] nation of problem solvers and a nation of innovators” [WL4(2010)].

5.5.4. Category 4: Biotechnology evokes ethical and moral considerations

In this category of experiencing biotechnology, the focus of attention is on the variation associated with ethical and moral consideration. In other words there are different ways of considering what is ethical or moral depending on the biotechnology practice with regard to the subject i.e. whether the practice involves animals, plants, insects or the environment. Furthermore, there is variation in considerations based on beliefs which include personal, community, religious, cultural and scientific beliefs. The characteristics of ethical and moral considerations are described below in the following subcategories: **considerations regarding subject of research** and **considerations concerning beliefs**

Considerations regarding subject of research

What characterizes this subcategory with regards to variation in ethical and moral considerations is the subject of the biotechnology practice. The variations in ethical and moral considerations concerning plants and food will be discussed first, followed by ethical and moral considerations relating to humans, insects and the environment.

Cloning plants was not acceptable to a number of participant communities and their beliefs, as is illustrated in this quote: "…unacceptable, like cloning goes against some religious people in my community including my family" [US30(2011)]. This is because ideas of both cloning and manipulating plants convey the association of humans playing 'God' and is further illustrated in these quotes: "Afraid of outcome, community against change and scientists seen as playing 'God'" [WS31(2011)] and "Religion thinks scientists are trying to 'play God'. Christians think that especially with cloning" [WFG1(2012)]. However, this technology is also associated with ethical and moral obligation to help humankind: "When I first started studying biotechnology I was a little sceptical about the manipulation of plants for better crop yield. I am of Jewish descent and most of my family does not approve of altering nature. The more I studied it, however, the more I see that ensuring a reduction in famine is far better, morally, than being able to do it and neglecting to do so"[WS16(2010)].

Another ethical and moral consideration associated with plants and genetically modified foods is the issue of commercialization and monopoly of genetically modified plants and foods by global companies, as is illustrated in the subtext of the following quote: “Genetically modified (GM) foods are fine as long as they are used for community benefits with less capitalistic mind e.g. the “knockout maize” - farmers could not replant the following year as no seed to harvest” [WL2(2010)].

With regard to genetic modification in plants, the gene transferred is also of concern, especially because an animal gene in a plant may not be acceptable in certain cultures or religions. The following quote illustrates this; however it also highlights the anecdotal and far-fetched issues related to the technology, as snake genes have never been considered for genetic manipulation in plants: “The use of GMO in food. Telling people in my community that its possible for them to eat rice that has been modified with a gene from an animal example such as a snake could sound very ill-mannerd (sic)” [US38(2011)].

Strong ethical and moral considerations prevailed when it came to animals and biotechnology practices: “… things like cloning animals, I’m against them” [WS22(2011)]. Other more explicit quotes include: “Probably animal testing would be the one that makes me very uncomfortable since what makes us the ones to be superior and utilize these animals for our safety. Its unethical and unfair” [WS3(2010)] and “(t)he injection of livestock to induce rapid growth or milk production in cattle is not acceptable” [WS6(2010)]. The latter quote also highlights, that amongst the participants in this study there was resistance to growing proteins useful to developing medicines in animals.

In contrast, what also came to the fore included the view that: “God helps people who help themselves” [WL2(2010)], i.e. we have developed the technology to use to help ourselves, so we should use the technology. This is an interesting view which is extended in the following quote: “Biotechnology practices are acceptable because religion is the study of the creator and science is the study of creation” [WS35(2011)]. The participants seemed to feel that as the technology to build the future was available, they were in favour of using biotechnology knowledge to build the future. The deep philosophical issues here include the conflict between the ideas of religion and science in the minds of the participants and in some cases it is evident that participants attempt to integrate their religious knowledge with science as is seen in the latter quote, as a way to reduce or resolve the conflict in ideas. Others reduce the conflict in the ideas between religion and science by allowing what they learn in the one to facilitate learning in the other area (simultaneous collateral learning (Jegede, 1997)) as is illustrated in the following quotes: "Science helps religion have a place" and "The intricacy is beautiful it is a confirmation of God" [WFG1(2011)]. Then there are issues where one worldview challenges another idea from a different worldview and actually restructures the existing worldview as is seen in the subtext of the following quote: "Biological sciences have led us to the mind of our creator" [WFG1(2011)], i.e. the worldview of the student becoming modified by the ideas associated with a scientific worldview. However, there are also participants who consciously compartmentalize the ideas, as in parallel collateral learning (Jegede, 1997). The following quote illustrates this: "Completely religious people do not bring these ideas to class they leave them outside….. but science is discovering how God thinks, if he exists and how he created this planet"[WFG1(2011)].

There were participants who would hesitate to or would not tell the community about testcrossing fruit flies, which is a practical laboratory exercise done in the third year Genetics practical sessions (WITS). These fruit flies are laboratory model organisms used to study genetics and genetic linkage (wild type and mutations). The reason for this is that there were beliefs among participants that in their communities testing and experiments on insects are cruel, unethical and morally unacceptable.

When it came to the environment and society the variation in ethical and moral considerations was mostly concerned with moral obligation to do the right thing for humankind and the future: "Alternative ways of product production at an industrial level which does not use as many chemicals as traditional methods. It is also safer for the environment and causes less pollution" [WS1(2010)]. Also for example when questioned on beliefs regarding GM food, an illustration of moral argument or obligation can be seen in the following quote: "I think they are necessary to prevent people from starving. The world is over populated and traditional farming methods won't meet the demand of the human population, so science, biotechnology and GM foods are needed in order to feed us" [US10(2011)].

Considerations concerning beliefs

Student participants only shared what they believed their family and communities could relate to and understand in the context of their cultural and religious beliefs. This was seen even with regard to what microorganisms were present in food produce: "I don't think I will tell my family that there are many fungal substitutes in certain products. This is something I wouldn't mention as even though they are vegetarians fungi are considered alive, so I definitely wouldn't tell them even though they should know" [WFG3(2012)]. According to Timmer (2010) large segments of a population choose not to accept scientific data because it conflicts with their predefined beliefs, whether economic, political or religious.

The use of GMOs and manipulation of DNA were seen to contradict the religious beliefs of communities, where the sanctity of life referred to all life being sacred, and as such any manipulation by humankind to any living organism was regarded as unethical and not morally acceptable. According to participants community beliefs were different from scientific beliefs because people in the community did not understand what DNA or a gene was: "Not many people believe in the gene or understand what DNA is" [US19(2011)]. The student participants seemed to feel that biotechnology practices are believable if they are understood, because according to them understanding could lead to acceptance. In many cases, however, according to most participants complex concepts did need visible proof and practical evidence. There were participants who only supported scientific reasoning, such as is illustrated here: "Don't believe in non-scientific beliefs that can't be proven" [US39(2011)].

In African communities, Sangomas[8] are consulted because of family background and an ethical and moral consideration to listen to one's elders. However, with a biotechnology background

[8] Sangoma is a Zulu term that is colloquially used to describe a traditional healer. Traditional healers are practitioners of traditional African medicine in Southern Africa (Van Wyk *et al*. 1999) ,There are two main types of traditional healers with differences in practices: an inyanga (the herbalist) is mainly concerned with medicines from plants and animals i.e. traditional medicines called muti, and a sangoma (the diviner) uses spiritual means to provide a diagnosis (Richter, 2003). According to Cunes (2004) these healers are effectively South African shamans who are highly revered and respected in a society where illness is thought to be caused through neglect of the ancestors, or through pollution due to contact with impure objects and occurrences, or due to witchcraft. Richter (2003) argues that the distinction between the two have been blurred because of colonialism, urbanisation,

the participants have begun to question these practices, in other words there is conflict between the two worldviews, African vs. Science. The moral obligation to follow the example of and to listen to one's elders is part of the African worldview and epistemology, which according to Jegede (1997) is anthropomorphic, ritualistic and metaphysical, which is interwoven with tradition and religion. The elder's repository of knowledge is the truth which is not to be challenged. With the participants' experience of biotechnology, they felt that: "people [in the community] just believe what they are told" [WFG3(2011)] and thus it follows that if the grandfather goes to a Sangoma, so will all males in the following generations. In the focus groups the participants argued that Sangomas use herbs without knowing the side effects. However, according to focus group discussions the Sangomas do influence the communities: "Traditional healers (Sangomas) regarded with respect, but we now with biotech knowledge question what they put in their concoctions" [WFG4(2011)].

It emerged that the participants felt their scientific knowledge should guide them to work with Sangomas getting a balance between their scientific knowledge and the traditional knowledge: "The Sangomas are the people of influence in our communities. And they therefore must be part of the solution" [WFG1(2011)]. The participants (both lecturers and students) felt they could make the transition, by promoting their new knowledge. This was supported through discussion in focus groups: "We should balance – we should play a role because our scientific knowledge should guide and we should work together. We should make the transition. Promote what we know not criticize. (Laughs) The info should be in universities, because slowly it will change- it will happen as the older generation people die" [WFG4(2011)].

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apartheid and cross-cultural mixing and thus traditional healers tend to practice both the arts of the herbalist and the diviner. According to Truter (2007) it is estimated that there are 25,000 western-trained doctors compared to as many as 200,000 indigenous traditional healers in South Africa and according to the WHO (2003), an estimated 80 per cent of the population use traditional health services in many parts of sub-Saharan Africa. However, according to Liebhammer (2007) this is in conjunction with modern biomedical services. Traditional healers alternate between roles of diagnosing common illnesses, selling and dispensing remedies for medical complaints, and using spiritual means to provide diagnoses and providing solutions to spiritually or socially centred complaints (http://www.wits.ac.za/placesofinterest/lifesciencesmuseum/izangoma/indigenous%20healing/2884/the_function_of_diviners.html).

5.5.5. Category 5: Biotechnology perceived as provoking ambivalence

In this category the focus of attention is how experience of biotechnology is associated with provoking ambivalence**.** "Ambivalence" is where ideas or attitudes are conflicted. Two opposing ideas, attitudes or emotions at the same time were very common in a lot of the responses, together with a number of contradictions concerning biotechnology. Responses in interviews, on questionnaires and comments in the focus groups showed that often participants responded with conflicting ideas or attitudes. The variation in these responses was seen due to **cognitive conflict** or because of **misconceptions concerning biotechnology practices and products**. The characteristics of these two subcategories for provoking ambivalence are discussed below.

<u>Cognitive conflict</u>

Responses to the questionnaires and comments in the focus groups showed that often students' responded through cognitive conflict. For example responses to what the participants thought about GM food included: "Unknown health risks. Provide more nutrients" [US33(2011)] and "GM foods should be used in society but at certain levels. One should not have a whole plate full of GM foods for dinner" [US36(2011)]. An example of where GM foods were considered harmful, but palatable as in the following quote: "Some GM foods could potentially be harmful where as (sic) some are completely safe and make food more palatable, nutritious and easier to grow" [WS1(2010)]. The following quote is ambivalent merely because it is the response of a student studying biotechnology: "I don't eat them. Gross" [WS33(2011)].

The extracts that follow have contradictions in one sentence: "Personally I wouldn't want to be associated with any work that has to do with GM foods but from a scientific point of view and on an economics view they are a sustainable option" [WH5(2010)] and "I think genetically modified foods are needed in developing countries, but they should be carefully consumed because future consequences of GMO foods are not known" [US15(2011)].

Finally in the following quote, the subtext illustrates the conflicting worldview of the participant and the community where very conflicted attitudes to the phenomenon biotechnology are evident: "My community would be Horrified (sic) but I (sic) find it to be very very interesting" [US9(2011)]. When asked whether there were any biotechnology practices that made a participant uncomfortable, a lecturer responded "…Haven't been made uncomfortable in any way. The only thing I can say not uncomfortable. I have an awareness that some things can be bad while the general philosophy is GM be for the good of mankind while others it can be for the demise of mankind. This worries me, but I still do the research" [UL1(2011)]. This once again illustrates the cognitive conflict in ideas with regards to biotechnology research.

Misconceptions concerning biotechnology practices and products

The various ways in which biotechnology has ambivalence associated with it, is seen in that even with a negative image it attracts a lot of attention i.e. misconceptions and negativity about biotechnology as portrayed by media evoked the interest in many participants which led them to study biotechnology: "Misconceptions associated with biotechnology – reason to study and research it" [WL2(2010)].

The following quote in response to why biotechnology was chosen as a course has a misconception: "Curiosity! All I missed was to experience what biotechnology was after all the negative press on GM foods. Moreover, the love of organic farming played a role!!" [WH5(2010)]. The misconception is that biotechnology and organic farming are on opposite ends of the farming spectrum, and the ambivalence is in the fact that the participant chose to study biotechnology because of negative associations.

Generally, participants seemed wary of GM foods but very happy that they help the poor, with food and medicine: "Its (sic) a good way to provide food to less fortunate people, and cheap especially for countrys (sic) that are facing drought and war" [US19(2011)]. This response shows ambivalence in that GM foods are acceptable in feeding populations where food is scarce, but at the same time the future consequences are unknown: "Maybe it could result in cancer therefore causing more harm than good" [WS3(2010)]. One participant would not use GM foods in their family unless it was a "life or death situation" [WS4(2010)].

Most the students have slightly superficial reasoning when it comes to comments concerning GM crops. Furthermore, there seems to be a level of generalization amongst respondents which seems to be due to assumptions and anecdotal issues in some cases.

5.5.6. Category 6: Biotechnology perceived as having risk and harm potential

In this category the focus of attention is the variation in risk and harm potential that is associated with biotechnology. According to participants biotechnology is not inherently harmful, but has the potential to be harmful depending on what it is used for and how and why it is used. The variation here results from: a lack of understanding indicating that biotechnology knowledge must be well studied and understood, to avoid any harm that can result and to avoid not knowing the consequences of the research; the potential abuse of skills and techniques developed in biotechnology research i.e. if the knowledge falls into the wrong hands and unethical experiments are performed; due to the experimental nature of the technology, which could result in not being able to foresee possible harmful future results or outcomes; and finally to the type of genetic engineering technique used. These all fall into the following four subcategories i.e. **Lack of understanding**; **Potential abuse of skills and techniques**; **Experimental nature of the technology** and **Genetic engineering technique used.**

<u>**Lack of understanding**</u>

If not used correctly or fully understood biotechnology like any other scientific field can potentially be harmful. The participants were wary of GM foods because of a lack of understanding as to what they are and what modifications are involved: "…I need to fully understand what was done to the food and if it is harmful to me physically" [WS11(2010)]. The media's description of them as "Frankenstein foods" (Bisseker, 2000) also seemed to contribute as it implies that biotechnology is potentially harmful: "Many people are anti-Biotechnology (sic) purely because they are ignorant and they are making choices based on what the media etc. say and not based on the facts. I aim to elucidate those around me on my views on Biotechnology (sic)" [WS9(2010)]. The following quote highlights a media-generated misconception of genetically modified organisms always being bigger than normal: "…some of the products are scary when you think of the scenario, for example in our climate the chickens are small and I do not think it will be natural to get the products like chickens as big as a turkey, also normal sized corn vs. very large corn. That makes me very uncomfortable. It is scary" [UL4(2011)].

The variation in themes of response to and acceptance of genetically modified products as seen in the study, show the effect of worldview on the experience of biotechnology which affects the understanding and acceptance of the biotechnology practice. As far as beliefs, cultural or religious, that may have an effect on participant acceptance of GMOs, GM foods or products, it emerged that not all students and lecturers are comfortable with eating GM foods. The variation in the responses to the use of GM foods varies from using them without a problem, to uncertainty regarding the products to total rejection. The variation in response seems to be mostly due to lack of understanding and perceptions of the risk or harm that could be associated with these products and their long term effects: "Some of the long term effects of genetically modified crops have not yet been established but perhaps they could cause harm" [WS16(2010)], together with not really understanding the technology used: "A better understanding might help […] understand and have a different view on GM products" [US38(2011)].

The variation in the acceptance of the use of genetically modified products supports the discussion of the influence of worldview and sociocultural background and beliefs.

<u>The potential abuse of skills and techniques</u>

Biotechnology is seen as potentially harmful if utilized by the wrong people for the wrong purposes and unethical experiments are performed: "I think it can be beneficial or harmful but that depends on the intention of the person who is utilizing biotechnology" [WH1(2010)]. The following quotes highlight the variation in conception but still reiterate the harm potential: "Man has always harmed the earth in some form or the other (with or without biotechnology) for greed, so it remains to be seen whether its harmful effects outweigh the benefits and vice versa" [WH3(2010)] and "Yes, biotechnology, if in the wrong hands, can be harmful" [WS16(2010)]. There was an underlying fear of a possibility that biotechnology practices could cause widespread disease: "…biotechnology, if in the wrong hands, can be harmful. There is a possibility that genetically modified viruses or bacteria could cause widespread disease such as was done in a similar way with SARS [WS16(2010)]. Another concern was: "microorganisms and products could be used for biological warfare" [WS5(2011)].

Experimental nature of the technology

Biotechnology as a science does have an experimental side; it is this experimental nature that is associated with potential risk or harm perceptions: "If not used correctly or fully understood biotechnology like any other scientific field can potentially be harmful. Especially as biotechnology is a new and developing field which is very experimental" [WS1(2010)]. According to participants the long term effects of certain practices are as yet unknown, e.g. genetically engineered plants or pest control methods. Biotechnology was seen as potentially harmful if the micro-organisms used mutate and become harmful to humans: "Yes, e.g. some GMOs can run out of control and nobody knows their environmental effects, the long-term effects on both human and other organisms" [US13(2011)]. However, according to others possible consequences can be predicted and tested in laboratories: "Yes-carelessness in the field of biotechnology can possibly be harmful and lead to unknown future effects. However, in safe locations such as laboratories, possible consequences can be inferred and decisions to continue can be made. On the whole though, biotechnology has greater potential for success rather than causing harm" [WS9(2010)].

Genetic engineering technique used

Variation was seen in responses to the question "Would you use GM foods in your families?", where one participant said: "Yes, because food go (sic) through digestion our body do not take up DNA as a molecule but its broken down and only appropriate nutrients are absorbed into our bodies"[US40(2011)]. Here the technique used is of no consequence to the participant. Other responses which show rejection of any GM technique include: "Although I know that the Earth's resources are fast becoming limited and that people are dying of starvation, GM foods is the future to those problems but it is extremely difficult to accept this into our lives. I have more confidence in eating pesticide foods than GM foods because I've grown up on pesticide foods from the Earth not the lab. There is just too much stigma attached to it being "new food" rather than just food" [WH3(2010)] and "Scarey(sic), wouldn't wana (sic) eat them. Just the thought of someone tampering with food we already have to make it, i (sic) don't know technical" [US6(2011)]. Here participants showed concern in the techniques used to make the products.

Yet another participant recommended that they had to be approved and confirmed with evidence, as is supported in the following response: "It needs to be accepted by WHO and publically then I would have confidence in it. However I would be very doubtful if my loved one's had to consume it without any hard evidence supporting it" [WH3(2010)]. This statement supports the involvement of the participant's science epistemology in response to biotechnology practices in that the participant trusts the World Health Organization because of what it represents i.e. lots of research to prove the safety of consumables and trusted WMS scientists.

The potential risk perception that depends on the type of engineering technique used includes the concern of whether bacterial transformations (as described in section 5.5.1) or biolistics[9] are used: "Depends on the modification, for instance a nuclear transformation may spread through pollen whereas a chloroplast transformation is confined to the specific plants. If it is detrimental to the organism or to people consuming the products then I am against it. If it is not bettering the future then it is useless as well" [WS17(2010)]. Also it emerged that to lessen risk and harm, genes that are transferred should be from the same type of organism, i.e. plant genes transferred into plants. The transgenes in plants should not be animal or insect genes. Furthermore there was concern as to where the gene was actually inserted because of consequences due to mutations that could result: "The insertion of transgenes into organisms (esp. crops) - mainly due to the nonspecificity of some of the techniques and we don't know what genes we knocking out or whether we mutating a potentially harmful gene" [WS18(2010)].

Student participants were concerned that if exotic organisms were made that have no natural predators they could outcompete indigenous species and they could then affect the

[9] Biolistics, also known as 'Particle Bombardment' is where the gene of interest or piece of DNA is literally shot into the tissue to be transformed. This is carried out using an apparatus known as a gene gun. Tungsten or gold beads are coated with the gene of interest and fired, into the plant tissue. (http://arabidopsis.info/students/anna/biolistics.html. Access date: 8 January 2013)

environment negatively: “fungal and bacterial organisms introduced into environment may pose risk to other organisms” [WS18(2011)]. Other potential problems that student participants were concerned about included: “transgene outcrossing” [WS18(2010)]; the “chemicals used to study products in the lab can be toxic” [WS29(2011)]; “…may alter living conditions negatively” [WS13(2011)]; “Genetic modification and genes taken up by different genomes”; and “Unknown allergens in new products” [WFG5(2012)]. The concerns of the lecturer participants included: “Viral engineering could be dangerous” [UL2(2011)]; “Introduction of new species may lead to loss of indigenous species and loss of biodiversity” [UL3(2011)]; “…all cases should be examined separately” [WL4(2010)]; and “…people involved should always be qualified and understand the consequences” [WL6(2012)].

5.6. Interpretation and discussion of categories of description

A description of each of the six categories was presented in the previous section, so that the distinction between each could be clarified, and so that the variation in each could be highlighted. The structure of awareness and categories of description, that are established in the outcome space represent the qualitatively different ways in which biotechnology was experienced by the participants in the study, and it characterizes the target population. These are presented here in Table 5.1.

Table 5.1: This table illustrates a summary of the outcome space of the six hierarchically related categories of description for the phenomenon investigated.

Categories of description	
Category 1 • Biotechnology is associated with building knowledge	Rudimentary level
Category 2 • Biotechnology has powerful application potential	↓
Category 3 • Biotechnology leads to skills development	↓
Category 4 • Biotechnology evokes ethical and moral considerations	↓
Category 5 • Biotechnology is perceived as provoking ambivalence	↓
Category 6 • Biotechnology is perceived as having risk and harm potential	Complex level

Each category of description has something distinctive concerning how biotechnology was understood and experienced. Through these six categories of description of experience of biotechnology it has emerged that as a scientific discipline biotechnology has huge potential and is a growing field. It is valued for the knowledge it comprises and the opportunity that is presented for building or appropriating this knowledge for oneself and for society. However, these six categories reflect a degree of complexity in which there is a progression of sophistication, associated with epistemic features which are inherent in each category. These epistemic features have to do with how each category is valued and this is linked to a cognitive and emotional response which is described in detail below.

These six categories of description describe ways that participants collectively i.e. both the lecturers and students, experience biotechnology. The categories of description that have emerged have been arranged according to the perceived degree of sophistication of the experience of biotechnology from a less to a more complex level, as is illustrated in Table 5.1 and will be seen in more detail in Table 5.2. This progression of sophistication is evident in the nature of the categories themselves i.e. of how biotechnology is experienced. The progression is explained as follows: Knowledge and the type of knowledge built is intrinsic in all the categories. Thus it is the basic level on which the rest of the categories develop. Applications are developed using knowledge. Skills consolidate comprehension between the knowledge and application (i.e. the theory and the practical aspect). In other words, the building of biotechnology knowledge leads to being able to apply the knowledge and by applying the knowledge skills are developed. The acquired knowledge, applications and skills lead to ethical and moral considerations, together with issues of ambivalence because of cognitive conflict from a cultural, religious or scientific point of view and finally these experiences and their associated understanding of biotechnology allow for the recognition of potential risk and harm. The epistemic features are inherent in each category and become more complex and sophisticated depending on how biotechnology is valued, which is connected to a cognitive and an emotional response that is dependent on the worldview of the participants.

Thus the categories presented in the outcome space are logically related and structurally inclusive in their relationships as each category is dependent on other categories, linking the different ways of experiencing biotechnology.

The first feature of the outcome space is the two aspects that distinguish one category from the other i.e. the “what” and the “how”. The most decisive characteristic is the variation in experience of biotechnology which shapes the understanding of the phenomenon. The way biotechnology was experienced and thus understood was affected by a cognitive and an emotional aspect. This cognitive and emotional aspect distinguished each category of experience from the other. For me this brought a resonance with Bloom’s conceptions of the cognitive and affective domains of educational activities (Bloom, 1956), which are briefly explained in the next paragraph.

Bloom identified three domains of educational activities i.e. the cognitive, affective and psychomotor domain. Educationalists today (Forehand, 2005) accept that by teachers addressing Bloom’s taxonomy of learning behaviours the learner acquires new skills, knowledge, and/or attitudes**.** Bloom’s cognitive domain involves knowledge and the development of intellectual skills. The affective domain of Bloom's taxonomy includes how we deal with things emotionally, which include feelings, values and attitudes (Krathwohl, Bloom, Masia, 1973). I have adopted the idea of Bloom's cognitive and affective domains of educational activities as described here, and adapted them to suit the requirements for distinguishing between the categories of description.

Thus a cognitive aspect involving the acquisition and use of biotechnology knowledge could be used to distinguish between the categories of description. The depth of conviction in participant conceptions showed depth of emotion because of issues such as feelings, values, ethics and attitudes involved, thus I also included an affective aspect as a tool for the distinction between the categories of description.

Thus, the cognitive and affective aspects have been used to distinguish the emergent categories of description from one another. The cognitive aspect relates to "what" the experience and understanding of biotechnology was; and the affective aspect relates to "how" biotechnology was experienced and understood. The use of "what" and "how" here differs from the normal use of the terms in phenomenographic research, where "what" generally refers to content to be learned and "how" refers to the way in which students go about learning it. In either case they are intimately intertwined or conflated and are only separable analytically.

For each category of description the cognitive and affective aspects are conceived as follows:

1. Biotechnology is associated with building knowledge

Cognitive aspect: The information presented in the curriculum i.e. the discourse of biotechnology

Affective aspect: How participants receive this information i.e. how they relate to it.

2. Biotechnology has powerful application potential

Cognitive aspect: Use of information presented in the curriculum for a particular purpose

Affective aspect: How participants respond to this information

3. Biotechnology leads to skills development

Cognitive aspect: Comprehension between the knowledge and application leads to skills development

Affective aspect: How participants value this information

4. Biotechnology evokes ethical and moral considerations

Cognitive aspect: Distinguishing and differentiating the information

Affective aspect: How participants organize the information to suit their epistemology

5. Biotechnology is perceived as provoking ambivalence

Cognitive aspect: Synthesis of the information provokes different ideas

Affective aspect: How participants deal with internalizing values

6. Biotechnology is perceived as having risk and harm potential

Cognitive aspect: Evaluation involving a more critical outlook

Affective aspect: How participants characterize whether risk and/or harm can result from the biotechnology practices.

The cognitive and affective aspects are thus distinct characteristics that distinguish the categories of description from each other. These aspects as highlighted above are summarised in the fourth column of Table 5.2.

The second feature of the outcome space is related to the degree of sophistication of the experience of biotechnology in each of the categories as mentioned earlier. This feature is that the categories of description constitute a hierarchy that points to a progressive response i.e. one category presupposes the outcome of experiences in the previous category in the hierarchy. This hierarchy is related to the cognitive and affective aspects which indicate a progression from one category to the next. The students first have to encounter the knowledge and how it is constituted and applied – then as they respond they recognize the power of application and potential of biotechnology, but they may start to encounter discomfort due to worldview-based response, and then there is recognition of ethical and moral considerations, of ambivalence and of risk and harm considerations. The way participants respond depends on their worldview. Students with strong religious convictions for example, will be challenged - for them border crossing into the world and practice of biotechnology may be more difficult than for those who don't have the same moral or ethical considerations. For lecturer participants it appears that for some that by integrating cultural/religious knowledge with science knowledge conflict of ideas seem to be resolved or in others, knowledge is conscientiously compartmentalized i.e. parallel collateral learning. This will be discussed in more detail in the next chapter.

The outcome space presented in Table 5.2, in the next page, describes the variation in the ways of experiencing and engaging with biotechnology.

Table 5.2: The outcome space: categories of description of experience of biotechnology

Level	Category of description	Distinguishing characteristics	Variation in experience which shapes the understanding of the phenomenon: (1) Cognitive & (2) Affective aspects
1	Biotechnology is associated with building knowledge	Variation in ways of building knowledge included aspects relating to building new knowledge; to building on prior knowledge; the social aspects of knowledge and cultural aspects of knowledge.	(1)Information content (2)Receiving information
2	Biotechnology has powerful application potential	Variation in application potential: intrinsic and extrinsic value.	(1)Application/use (2)Responding to information
3	Biotechnology leads to skills development	Variation in types of skills associated with biotechnology: analytical skills, practical skills and problem solving skills	(1)Comprehension (2)Valuing the information
4	Biotechnology evokes ethical and moral considerations	Variation in practice with regard to the subject involved i.e. animals, plants, insects or environment. Variation in considerations based on beliefs.	(1)Analysis (2)Organizing the information
5	Biotechnology is perceived as provoking ambivalence	Variation regarding cognitive conflict or misconceptions concerning biotechnology practices and products.	(1)Synthesis (2)Internalizing values
6	Biotechnology is perceived as having risk and harm potential	Variation regarding lack of understanding; potential abuse of skills and techniques; experimental nature; type of genetic engineering technique	(1)Evaluation (2)Characterizing the information

This phenomenographic analysis has identified a variation in the ways in which the research sample relates to the general experience of biotechnology and biotechnology teaching and learning practices. What is significant about this result is the categories of description as they emerged take into account the sensitive nature of the experience of biotechnology, and thus is something that those involved in teaching and learning of biotechnology courses should be made aware of so as to enrich the biotechnology curriculum and to provide epistemological access for the learners.

The first three categories of description include a growing understanding and appreciation of science and where it can take the participants. The second three categories highlight an emotional response to what is being learned that is grounded in participant epistemologies. It thus became apparent, that the six categories could be meaningfully consolidated and represented into two broad categories of description, i.e. a category which considered biotechnology from a traditionally scientific perspective (biotechnology as a science), and the other which was a response from a worldview perspective.

5.6.1. Refined outcome space

The experience of biotechnology as a scientific discipline has emerged as a powerful culturally shaped body of knowledge that leads to two areas of response i.e. biotechnology is valued because of the knowledge, applications and skills it offers, however experience of biotechnology raises issues of ethics, morals, ambivalence and risk i.e. issues related to epistemology and worldview. This idea highlights a division in value between the six qualitatively different categories, i.e. categories 1, 2 and 3 can be grouped together and categories 4, 5 and 6 can be grouped together. The various structural features of the categories of description have been discussed, and Tables 5.1 and 5.2 have shown the 6 qualitatively different categories of description of the experience of biotechnology. Table 5.3 is a further refined version in terms of worldview theory and results in only two categories, i.e. the most parsimonious set of categories of description for experiencing biotechnology, which still represent the full range of possible ways of experiencing biotechnology collectively for the population represented by the sample group. The two main responses i.e. categories of description then to come out of this research on the phenomenon biotechnology is that it has a (1) Theoretical and practical perspective (which includes knowledge, applications and skills) and a (2) worldview perspective (which include moral, ethical, ambivalent and risk considerations).

Table 5.3: The refined outcome space

Categories of description

Category 1

Biotechnology has a theoretical & practical perspective

Category 2

Biotechnology has a worldview perspective

These two categories make up a more meaningful outcome space because the rationale behind the phenomenographic approach that was used for this investigation is that the research outcomes need to be amenable to practical implementation for pedagogical effectiveness. Thus the relationship between the quality of the categories of description and the variation in experience of biotechnology which shapes the understanding of the phenomenon can be regarded from a different perspective because of the pedagogical interest of the study i.e. to improve learning and understanding of biotechnology by informing development of the curriculum for epistemological access. From the perspective of the approach to pedagogy for epistemological access, each category of description is associated with the recognition of the level of understanding or experiencing associated with a certain type of cognitive and affective aspect, as described above in section 5.6. The reason for reducing the categories from 6 to 2 categories is so that is not too vague for practical pedagogical application but still has the specificity that makes it applicable to inform teaching and learning.

In principle the first category of description obliges deeper understanding as it provides information for development of the level of understanding associated with the more complex second category of description. This means that as the participants' experiences of biotechnology evolve from a less to more complex category of experience they are afforded a deeper level of understanding which in effect establishes a border crossing or not (discussed in Chapter 2). Cultural border crossing and collateral learning as pedagogic devices can serve in a practical sense as a response to what this phenomenographic method has produced in the outcome space.

Accordingly the outcome space has been re-articulated and refined and includes the approaches to T&L to provide for epistemological access. These approaches are linked to the "what" and "how" aspects of variation in experience of biotechnology which shapes the understanding of the phenomenon, as is described in the next paragraphs and shown in Table 5.4.

The first feature of the refined outcome space is the characteristics that distinguish the two categories of description from each other. The differences between each category include the cognitive and affective aspects. The cognitive aspect relates to "what" the experience and understanding of biotechnology was; and the affective aspect relates to "how" biotechnology was experienced and understood.

Category 1. Theoretical and practical perspective:

Cognitive aspect: Knowledge, application and comprehension

Affective aspect: How participants receive, respond to and value the phenomenon, biotechnology.

Category 2. Worldview perspective:

Cognitive aspect: Analysis, synthesis and evaluation

Affective aspect: How participants organize values to suit epistemology, internalize values and characterize information regarding the phenomenon of biotechnology.

The second feature evident in the categories of description is that they form a hierarchy, where category 2 presupposes the outcome of experiences in category 1:

The theory and practical perspective (category 1) affords awareness for receiving, responding to and valuing biotechnology. This value is expressed in what biotechnology can offer the participant and there is evidence of value diversity as it is sensitive towards individual and cultural differences. With this comes the ability to solve problems for social improvement and how this is done depends on the epistemology of those involved. Thus the approach to pedagogy for epistemological access for this category of description includes: Constructivism (discussed in section 2.3) which involves building knowledge using prior knowledge, indigenous knowledge and science knowledge; an awareness of techno-epistemology (as discussed in section 2.3), which transpires because technology as a human way of knowing is bound up with culturally specific practices (Van Eijck and Claxton, 2009); a consideration where knowledge, applications and skills developed are relevant to the African environment and the awareness of value in biotechnology in the participants' life-world and science world.

The worldview perspective (category 2) affords an awareness to organize values into priorities with ethical and moral considerations, ambivalence and risk and harm potential where the emphasis is on comparing, relating, and synthesizing values so that any conflicts can be resolved and by internalizing values a personal and social value system can develop. Thus the approach to pedagogy for epistemological access for this category of description includes:

Socio-cultural constructivism and an awareness of traditional, cultural and religious beliefs and socio-cultural background.

Because the participants' conceptions of biotechnology have developed from prior experience and their background, as described in Chapter 1 and 2, the variation of experience as described in Table 5.2 and re-articulated and refined in Table 5.4, also describes the variation in worldviews concerning biotechnology. Thus phenomenography as a methodology has allowed confirmation of what the literature says in terms of worldview theory. Phenomenography has a pedagogical imperative and using this methodology has promoted awareness of teaching and learning in biotechnology that focuses on the application of worldview theory, which includes the theories of collateral learning and learning through cultural border crossing. Consequently, the progression in the complexity of the experience of biotechnology has an effect on the development or not of border crossing and collateral learning.

Table 5.4: The refined outcome space: categories of description of experience of biotechnology

Level	Category of description	Distinguishing characteristics	(1) Cognitive and (2) affective variation in experience of biotechnology which shapes the understanding of the phenomenon	Pedagogical response to provide for epistemological access
1	**Theoretical & practical perspective**	Biotechnology is associated with building knowledge, Biotechnology has powerful application potential, Biotechnology leads to skills development.	(1)Knowledge, application and comprehension (2)Receiving phenomenon, responding to phenomenon, and valuing phenomenon.	Constructivism Techno-epistemology Courses relevant to African environment with the aim of providing African solutions for Africa
2	**Worldview perspective**	Biotechnology evokes ethical and moral considerations, Biotechnology is perceived as provoking ambivalence, Biotechnology is perceived as having harm/risk perceptions.	(1)Analysis, synthesis and evaluation (2)Organizing values to suit epistemology, internalizing values and characterizing the phenomenon	Socio-cultural constructivism Acknowledgement of traditional, cultural and religious beliefs/ socio-cultural background

The better the understanding of the theoretical and practical background of biotechnology practices the more it appears that participants can adapt their worldview perspective. As discussed in Section 1.5, although there are fundamental cognitive differences among people, it does not mean that every cultural or social difference is the result of a different worldview, what it means is that a worldview can elicit various different perceptions of a concept, depending for example on factors such as the environment in the science classroom (Cobern, 1996).

5.6.2. Summary of the outcome space

The phenomenographic analysis of how students and lecturers experience biotechnology identified biotechnology as being valued for the useful knowledge associated with it, application potential and skills development potential. At the same time issues of ethics and morals, issues of ambivalence and issues of potential risk and harm were raised, resulting in two broad categories of description in the outcome space. Because the phenomenographic focus is on the collective, lecturer and student participant responses were all regarded collectively.

The experience of biotechnology as having a theoretical and practical perspective affords an approach to pedagogy for epistemological access that builds on the principles of new, prior and indigenous knowledge i.e. constructivism. Thus providing an understanding of biotechnology, with its associated techno-epistemology, and with a worldview consideration where knowledge applications and skills developed are relevant to the African environment and there is value in the biotechnology in the participants' life-world and science world.

The variation in each category of description of the experience of biotechnology is speculated to be associated with the socio-cultural background of the participants. The acknowledgement that biotechnology like any other science requires awareness of potential cognitive conflict affords lecturers the opportunity to enable epistemological access, through awareness of traditional, cultural and religious beliefs and background and associated value systems to develop an understanding of moral considerations that impact on learning.

Research based on socio-cultural constructivism indicates that worldview and furthermore how the T&L of biotechnology is experienced has an outcome to inform development of the curriculum for epistemological access. Thus, making or proposing a biotechnology curriculum that recognizes the need for sensitivity allows for the development of a contextually relevant curriculum where examples should be appropriate to local environment and reference is made to indigenous beliefs and knowledge in a way that allows for border crossing and the development of what could be called an African product.

The implication of the findings of this phenomenographic research study is that the significant qualitatively different ways of experiencing biotechnology are associated with worldview considerations. This implication links up with the research questions that were posed and is discussed in more detail in the next chapter. The knowledge of biotechnology is sought after by many of the participants because of a growing understanding and appreciation of science and where it can take them. Knowledge is seen as giving powerful skills which lead to careers and empowerment to help community. On the other hand though it provides issues of values which concerns the moral obligations tied to worldview concerns and epistemological background. Thus how this knowledge is seen as "empowering" seems to be associated with worldview, which highlights worldview as something that is not necessarily static, but that it can be dynamic, with tertiary education providing the opportunity to engage in a mindful way, i.e. with the knowledge there is an opportunity for understanding and reflection on the use of biotechnology concepts and practices. This research study has highlighted what the benefits of science are at a personal level in terms of preparing for a career, and at a values level, where the science may provoke discomfort because of cognitive dissonance. What this study has done is to ask what the people think and feel about biotechnology, thereby democratizing the curriculum and opening the space for a culturally relevant curriculum in a world that both desires, demands and pushes science, and in Africa where there is a need to retain an identity, pushing against hegemony and colonialism, thus highlighting the tension between WMS and an African identity.

Furthermore, within the categories of description the undercurrent theme is of the need to identify ourselves as an African University, where output is regional and for the benefit and development of the community, which is supported in this quote: "…now we need to investigate deeper in our own regions and become an interconnected SADC. Regional collaboration has huge potential. …As academics we need to share our ideas and collaborate". [WL2(2010)]. The need to identify ourselves as an African University is because a university should respond to the needs of society. This view was affirmed by a lecturer who said: "Think global, act local. This has to do with local challenges and local advantages because we need to ask ourselves “Can we really cure AIDS?” “Can we run multimillion dollar genome projects?” Can we do all of that? No we can’t compete! We need to concentrate on developing local biotechnology within our means, starting off in humble beginnings. We cannot become a world leader in one thing and compete with the West if we can’t fix our home-grown problems” [WL4(2010)].

5.7. Conclusion to Chapter 5

Phenomenography as a methodology has allowed for the emergence of two categories of description with regard to how participants respond to the phenomenon “biotechnology” i.e. there is a theoretical and practical perspective and a worldview perspective. Because of the pedagogic aspect, cultural border crossing and collateral learning, which are cognitively based theories of learning of how an individual will respond to something, can serve as pedagogic devices that practically serve as a response to the two categories that have emerged in the refined outcome space. This study has highlighted the existence of tensions in the context of T&L of biotechnology which support the science education literature that highlights the impact of worldview in teaching and learning science. In the following chapter these two categories of description will be considered in relation to the literature, and discussed in the light of contributions that could be made to the biotechnology curriculum and the imperative in southern Africa, to provide for epistemological access.

Chapter 6 – Discussion and conclusions

6.1. Introduction

The phenomenographic approach used in this study has allowed for the emergence of a number of ways in which participants engaged with and responded to biotechnology. As such, the categories of description to emerge in the refined outcome space include, firstly a growing understanding and appreciation of science and its potential in terms of the participants lives both on a personal level and within their communities, and secondly an understanding of biotechnology in relation to worldview. The study provided a space for the participants to consider biotechnology in relation to their own set of values. Here it was apparent that their emotional responses were grounded in their values and these were determined by their worldview. The implications of these two categories of description can inform pedagogic practice in biotechnology. Those involved in the teaching and learning of biotechnology courses would benefit from awareness of the findings which would help them provide epistemological access through reshaping their curricula to be culturally sensitive. This is especially important in a multicultural context, such as the context in which this study was done.

This chapter starts with an overview of the findings. This is followed by a discussion of the outcome space in relation to the literature. Biotechnology tertiary education at the two universities is then considered. The following sections then include recommendations to inform the development of a biotechnology curriculum by: firstly, considering the experience of the biotechnology curriculum with recommendations for ensuring epistemological access; secondly, considering cultural border crossing and collateral learning; and then thirdly, the section is concerned with recommendations for the successful implementation of cross-border tertiary education that is relevant in the African context. The chapter then moves on to include the methodological findings, the limitations of the study and recommendations for future research.

6.2. Overview of findings

Biotechnology as a science has become increasingly important in the context of everyday life, especially in terms of its potential to address global problems such as food security for all. For universities the presentation of well-developed biotechnology courses provides the opportunity to assist in capacity development which can lead to solutions to such issues. The imperative for universities to become involved in such capacity development is driven by the following: firstly, the Council on Higher Education (CHE, 2007, p11) requires that, in terms of its transformation agenda, universities respond to the needs of society. McKenna (2012, p15) argues that in South Africa the idea of transformation as a 'conception of quality' encompasses transformation of institutions and of society. She further points out that the transformation of society in South Africa has important implications for the work of academics, especially with respect to the inequalities associated with South Africa's past. Curriculum development can thus be seen as an important contribution by universities in meeting the need for transformation and capacity development for the benefit of society.

Secondly, the aim of 'Vision 2030', the policy framework in Namibia, is to produce a knowledge-based economy in Namibia; and the aim of the South African DST is to drive transformation towards a knowledge-based economy with associated economic benefits. The DST's vision includes South Africa becoming a world leader in biotechnology and pharmaceuticals, based on the nation's indigenous resources and expanding knowledge base. However, with this recognition of rich IKS in southern Africa and its potential to help South Africa to become a world leader in such fields, the use of this IKS has to be recognised as being potentially exploitative. Our constitution is especially protective with regard to intellectual property (IP) and for this reason there is a need to develop a curriculum that is contextually responsive, responsible, and respectful to indigenous knowledge and indigenous people which at the same time is economically beneficial to the country. Such a curriculum needs to be designed to not only benefit indigenous people and to protect their IK but to also provide for the economic benefit of the communities involved.

Thirdly, the neoliberal effect of globalization has led to universities doing research that is valued for its application and marketability. University work is thus becoming more about developing human capital and what Drucker (1996) calls the development of a 'knowledge economy'. According to McKenna, (2012, p17) this refers to thinking about knowledge as "a product that has currency". Shore (2010, p15) describes this change in thinking as universities transforming from places of 'critical inquiry' to businesses needing to compete in the 'global knowledge economy'. Knowledge has become a product that universities produce, package and sell (McKenna, 2012). The 'blurring' of national boundaries brought about by globalization has meant that universities need to respond to international trends in knowledge creation and development (McKenna, 2012, p17). They are also becoming more competitive in terms of the need for monitoring and measuring excellence with 'quality assurance' 'performance management' and 'international benchmarking' becoming increasingly important (Shore, 2010, p16).

Biotechnology as a discipline not only has the capacity for enormous contribution in the medical, industrial and agricultural sectors; it also has a social science side which must be involved in discussions among those involved in the T&L of biotechnology. Therefore the biotechnology curriculum that needs to be developed for southern Africa should respond not only to global trends but also to the local social context. The need to include the effects and benefits to society was poignantly highlighted in this study, where participants spoke of their regard for the science, but also their concerns related to their values.

Fundamental to building a knowledge economy is that there needs to be a link between science, society and democracy. Qin and Brown (2007) suggest that a knowledge society can only be accomplished if the public and government are well informed about science, so that they can be involved in decision-making processes. Lecturer participants in this study confirmed that communication between the DST and the tertiary education sector in South Africa, and between NABA, DART and the tertiary education sector in Namibia, should be involved in discussion regarding the knowledge economy so that the institutions can develop appropriate courses for capacity development and invest in research and innovation in a resourceful way. The findings of this study emphasize the need for WITS and UNAM to identify themselves as African Universities and provide African solutions to African problems. In other words, "output" should be regional, yet still mindful of global developments for the benefit of local communities. This accords with these universities to respond to the needs of society, addressing developmental issues in these regions through curricula that are sensitive to African epistemologies and worldviews.

In terms of the pedagogical implications of the study, the two categories of description that emerged indicated the need for a constructivist approach to teaching and learning and the need for a contextually sensitive curriculum. The theoretical and practical perspective, which is associated with the knowledge, empowerment and skills development offered by biotechnology, points to the need for a pedagogical approach which involves building on the students' prior knowledge of science. However, the findings clearly indicated another dimension to the issue of epistemological access, which was the impact on learning of students' prior knowledge, based on their worldview. The implication here is that teachers would need to be aware of cognitive conflict and adopt a socio-cultural constructivist approach to the presentation of course materials, rather than simply a constructivist approach. A socio-cultural constructivist approach would include aspects of building knowledge that relate to building new knowledge on prior knowledge and taking the social and cultural aspects of student knowledge into consideration during the teaching process. Underpinning the T&L should be a culturally sensitive and contextually relevant curriculum.

6.3. Discussion of the outcome space in relation to the literature.

In the refined outcome space presented as Table 5.4 in Chapter 5 the two main categories of description that emerged from the phenomenographic analysis were that the collective experience of biotechnology involves (1) a theoretical and practical perspective and (2) a worldview perspective. In this section these two categories will be considered in relation to the literature.

6.3.1. Theoretical and practical perspective of biotechnology

This category of description will be discussed in relation to the literature with regard to a number of distinct areas: the first concerns a number of perceptions associated with biotechnology to emerge from the study; the second concerns the need for acknowledgement of indigenous knowledge systems (IKS); and the third concerns the inclusion of biomimicry in biotechnology topics.

6.3.1.1. Perceptions associated with biotechnology

As discussed in the literature review, public perception of biotechnology is extremely complex. Qin and Brown (2007) argue that there are differences in perception with respect to biotechnological products and services depending on age, gender, education and culture. These perceptions can vary and in some cases biotechnology practices can even be seen as threatening, as elucidated by one of the student participants: "….. My school and family think it is very alien (especially Plant Genetic Engineering) because they have certain misconceptions about it that cannot be changed. They are of an older generation so new technology is threatening rather than exciting" [WH3(2010)]. Further concerns relating to perceptions associated with biotechnology include methods of genetic engineering; the terminology associated with biotechnology; and perceptions related to the global knowledge economy. Each will be discussed in relation to other research studies in this field.

Genetic engineering methods

The data collected in this research study showed that student perceptions of genetic engineering vary according to the type of application used i.e. whether animal or plant modifications were being considered. A study on Brazilian student attitudes to genetics and biotechnology by Massarani & de Castro Moreira (2005) found that genetic testing applied to animals in order to produce organs for transplant was not deemed acceptable. This was supported by my findings where participants expressed distress and disapproval with regard to animal testing: "...if I hear about products being tested on animals, it can be heartbreaking (sic). I rather not be involved when it comes to animals being tested on for human/consumer products" [WS24(2011)]. A study by Črne-Hladnik *et al.* (2009) in Slovenia involved testing perceptions with regard to genetically modified organisms. Plant modifications were found to be more acceptable than any modifications to do with animals. Frewer *et al.* (1997) demonstrated that consumer perceptions of GE foods varied according to the type of application and according to specific application within the same type of organism. These findings were borne out in my study: with regard to plant transformations where the type of genetic modification was also an important consideration i.e. a nuclear transformation vs. a chloroplast transformation. In my study participants were happier to accept chloroplast transformations than nuclear transformations. Participant perceptions were also found to vary according to the specific applications within the same type of GMO e.g. rice which had added vitamin A was more acceptable than herbicide resistant rice. Rommens *et al.* (2007) point out that genetic engineering, despite widespread media coverage, continues to spark consumer concerns. They claim that public perceptions centre around issues to do with transgenic or xenogenic[10] engineering of food crops. Generally, according to participants in my study, the transgenes in food crops should not be foreign genes such as animal, insect or synthetic genes i.e. xenogenic engineering. However, transgenic engineering, i.e. the transfer of plant genes into other plants, was acceptable. Rommens *et al.* (2007) suggest that this all-native DNA transformation could at least theoretically be created by conventional breeding. Therefore they argued that these transformed plants should not be associated with the production of unknown toxins, allergens or anti-nutritional compounds. It was apparent from my study that if participants understood the genetic modifications result in clear and transparent benefits to consumers, they could be accepted and supported.

While none of the GE practices discussed in class made participants uncomfortable in terms of their learning to be scientists, there was not unanimous approval of GM foods. From the literature, public support for GM crops in the USA has remained at the same low levels over the past decade (http://pewagbiotech.org). According to Rommens *et al.* (2007) this lack of support can be attributed to NGOs such as Greenpeace, who discourage the production and sale of GM crops.

While biotechnology has many benefits, it does not always enjoy a good reputation. Often this is due to a lack of understanding or misunderstanding. Borbone (2009) suggests that scientists come across as dogmatic and superior, which produces mistrust among the public. Qin and Brown (2007) agree with this by claiming that trust is a major determinant of attitude towards new technologies. In his paper on “the tacit epistemology of the GMO debate”, Borbone (2009) suggests that the answer to the question of biotechnology mistrust has to do with the issue of

[10] Transgenic plant is a transformed plant containing a DNA fragment or gene from a bacterium, animal or a different plant family. A xenogenic plant is a transformed plant carrying synthetic DNA.

tacit epistemology i.e. the way the scientists themselves understand biotechnology. The opinions of policy makers and of the general public rely on their tacit epistemologies as well, so the theoretical and scientific motivations that make up the foundations of biotechnology could be misunderstood because of uninformed opinion (Ibid.).

In my study participant perceptions often included ideas that were sometimes bizarre misconceptions. For example it was stated that:

- GM foods lead to obesity;
- GM foods cause change in growth patterns in children (children exposed to GMO supposedly grow and mature faster);
- GM foods have negative health ramifications (e.g. GMOs are responsible for causing cancer);
- Organs could be grown and harvested in live animals;
- GM chickens “grow big” (can be harvested) in 2 days;
- GM chickens can “fit on a skewer easily” i.e. “no legs and no beaks”, they have been genetically modified to comprise a mass produced body (a misconception from adverts on the Internet regarding KFC chickens (http://www.snopes.com/horrors/food/kfc.asp));
- Biotechnology involves eugenics being practiced on humans.

The terminology of biotechnology

The language and terms used to describe concepts are critical in constituting meaning. The meaning given to a term determines how it will be perceived, and terms such as genetic engineering and genetically modified foods have frequently elicited negative reactions or even fear. The following quote in response to “what do you think of genetically modified foods?” illustrates this: “Scarey, wouldn’t wana (sic) eat them. Just the thought of someone tampering with food we already have to make it, I don’t know technical (sic)” [US6(2011)].

However, Qin and Brown (2007) have suggested that public reading of GMO information generally leads to a positive change in attitude. They argue that the way information is presented to the public, together with the use of certain wording, can lead to the acceptance or rejection of certain concepts such as genetically engineered foods. Some words associated with biotechnology have been found to be more acceptable than others and have aided understanding, for example the word ‘biotechnology’ was seen as less provocative than the use of ‘genetic engineering’ and ‘genetic modification’ (Ibid., p472).

The language used in biotechnology and how this language describes the actual genetic engineering technique thus leads to different perceptions of the applications associated with biotechnology. In recognition of this, Nielson (2003), in order to prevent any misunderstandings regarding the process of plant transformation, defined plants transformed with native DNA as intragenic, and those transformed with DNA from the same family as famigenic[11]. These terms were constructed to distinguish genetically modified crops based on the distance between the DNA source and the target crop. The terms were specifically constructed to provide clarity with regard to the process for consumers, NGOs and agricultural biotechnology companies. Another example comes from Qin and Brown (2007, p484) who suggested the idea of “consequence” information vs. "perspective" information. In their study, consequence information explained the result or the effect of the technology and seemed to give the public a higher level of confidence in their own judgment and had a greater impact on the reader. Perspective information gave the viewpoint of various stakeholders on the technology. Qin and Brown suggested that consequence information should be considered for future communication to the public about GE foods, because the main issue for consumers was that they wanted to know the outcome of the technology, and what the consequences could be. Student participants in my study often commented about wanting to know the consequences, for example: “I think genetically modified foods are needed in developing countries, but they should be carefully consumed because future consequences of GMO foods are not known” [US15(2011)].

There are various issues such as those relating to human and animal health, safety consideration and the specific applications of the knowledge that need very careful

[11] A famigenic plant is a transformed plant developed using DNA from a sexually incompatible plant from the same family.

consideration. The descriptions and terms used for the genetically introduced genes should make it clear to the public or consumer what genes were used for insertion and how they were inserted. This section has highlighted the sensitive nature of both the way the information is presented and the terminology that is used.

Global knowledge economy

When considering the concerns around biotechnology, there is often a blur in understanding such concerns being linked to problems involving public and environmental health or being linked to pressures created by multinational companies to sell their products. Jean-Pierre Berlan, Research Director of the Institute of Montpellier in France in 2001, stated that modern biology and biotechnology "are a part of financial speculation characteristic of our epoch" (as cited in Borbone, 2009). The economic interests associated with investment by massive companies that monopolize the biotechnology sector may undermine the judgement of independent evaluation companies. Notwithstanding the power of such big multinationals dealing with biotechnology, there are reactions in terms of concerns around risk evaluation and policy development relating to the products. In Africa, the Cartagena protocol[12] on Biosafety, a policy on genetically modified organisms (GMO) and genetically engineered (GE) foods, is strongly supported, with a majority of the countries as signatories. In addition, several African countries have, in the past, rejected aid (especially unmilled grains) in food imports because of concerns for national biosafety (http://maps.grida.no/go/graphic/africa_policy_on_genetically_modified_organisms_gmo_and_genetically_engineered_ge_foods).

The pressure of globalization and western hegemony on Africa leads to perceptions of inferiority. Exposure to Eurocentric cutting edge research and technology means that Africans

[12] "The Cartagena Protocol on Biosafety to the Convention on Biological Diversity is an international agreement which aims to ensure the safe handling, transport and use of living modified organisms (LMOs) resulting from modern biotechnology that may have adverse effects on biological diversity, taking also into account risks to human health. It was adopted on 29 January 2000 and entered into force on 11 September 2003"(http://bch.cbd.int/protocol/ [Access date: 22 January 2013])

may be held back from finding African solutions for African problems because of the belief that western ways of knowing are superior to those of Africa. Following Lewis and Aikenhead's (2000) argument about the impact of Eurocentrism leading to non-western cultures being regarded as inferior, African inferiority complexes can be related to the global knowledge economy. The power of globalization and western hegemony is such that in this study it was clear that participants enjoyed the reinforcement and confirmation of knowing they were learning what was being taught in other countries, especially countries in higher economic brackets. For example students at UNAM expressed comfort in the fact that they were learning the same information as students at WITS. This can be seen in the following quote: "When Mrs X lectured us, esp. when things sound familiar (what we have done before); it kind of assured me that we are not the only ones doing it" [US12(2009)].

6.3.1.2. Indigenous Knowledge Systems (IKS)

The use and practice of technology by humans for survival in a challenging world is the basis of biotechnology. Biotechnology can be associated with indigenous knowledge, as is evident in communities managing their own sustainable crops, brewing their own drinks and fermenting milk product. Globalization has had a positive effect on southern Africa in terms of causing awareness of the huge potential of the indigenous biota, the huge potential in developing resources, and the economic benefit associated with exporting biological products.

The development of appropriate GMOs that lead to sustainable agriculture and use indigenous knowledge (IK) and practice for the development of a knowledge based economy brings with it issues of public participation and indigenous knowledge systems (IKS). The next few paragraphs give evidence of the sort of home grown research being done in southern Africa based on IKS.

According to Ferreira (2010), a botanist at the University of the Western Cape (UWC) in South Africa has launched a project to extract unique compounds from a common shrub, kraalbos (*Galenia africana*). This shrub thrives in the arid areas of the Western and Northern Cape. It was used traditionally by indigenous tribes who chewed the plant to relieve toothache, as well as for treatment of skin diseases, venereal diseases, and inflammation of the eyes. This led to the scientific verification of antifungal activities which then led to the development of an antifungal spray for vegetables and fruit. The kraalbos extract has a reputation as an effective anti-dandruff shampoo and is also used in a soap called “Namaqua Gold”. Furthermore, it is used in a skin ointment to treat psoriasis, a medical condition involving red and dry skin. An unexpected additional benefit of the extract is that tomatoes sprayed with it have improved nutritional value (Vries *et al*., 2005). The use of kraalbos extract is an example of synergy between science and IKS, where scientists have seen potential and exploited it for benefit. The researchers are in the process of creating a commercial product and have taken out a patent. In accordance with the Biodiversity Act, the UWC is negotiating benefit agreements with the Namaqualand communities whose ancestors discovered the properties of the plant (Mativandlela *et al*., 2009). A contract like this one was signed by the San Bushmen with the Council for Scientific and Industrial Research concerning hoodia when it was developed into a diet drug. In this case, the landowners who supply kraalbos also stand to gain. The shrub is loathed by livestock farmers as it can be toxic to sheep and goats, but it plays an important role in stabilising the dry top soils of the overgrazed plains of Namaqualand, thus allowing other vegetation to re-establish itself (Van der Lugt *et al.,* 1992). The scientists are trying to make it into an economically valuable crop for small-scale farmers so that it has the double benefit of stabilizing the soil and making it fit for other uses as well. Researchers at Pretoria University are studying kraalbos extracts as a treatment for tuberculosis, but clinical trials needed to do this are complex and expensive (Ferreira, 2010; Mativandlela *et al*., 2009; Vries *et al*., 2005; Van der Lugt *et al.,* 1992).

One of the DST’s plans as mentioned previously is to develop South Africa into becoming a world leader in pharmaceuticals. Here IK plays a pivotal role as in the case of developing ethno-medicines. Ethno-medicines are compounds from indigenous plants in southern Africa. These indigenous plant products can be used for example as drugs to target different strains of HIV. According to a lecturer participant who had developed an interest in the subject traditional healers in Namibia have come up with 4 plants that are believed to lower viral load in HIV infections. Scientists at UNAM are trying to validate the efficacy of the plants used by the traditional healers. The researchers are also screening other plants for anti-HIV properties. UNAM have signed agreements with the traditional healers, so that the issue of Intellectual

Property (IP) is being respected. This is important to protect the traditional healers' indigenous knowledge as access and benefit sharing laws are not yet established in Namibia. There are only biosafety laws in place.

In terms of IK, the need to sustain local genetic diversity was a concern to participants in the study. It was felt that indigenous crops are the future crops of Africa and that subsistence farmers are the backbone of food security. In response to the question "What are your thoughts on using GM Foods? Do you use them?" one of the Namibian lecturer participants said: "If enrich the health nutrition then yes and if cheaper than the other, then yes. If subsistence farmers benefit as they are the backbone of food security, then yes. But then in reality a yes is not acceptable because of issues of commercialization, accessibility and sustainability. In subsistence farming landraces are more important than hybrids. Because of the genetic diversity, we lose it as develop more and more hybrids (sic)" [UL4(2011)]. This view supports the argument to preserve gene diversity of landraces[13] and not breed GE crops that are too similar, and in so doing lose the genetic diversity inherent in landraces. This draws on ecological principles related to biodiversity and it draws attention to the compensation of intercropping (practiced by indigenous communities) vs. monoculture (practiced by large commercial companies) and of subsistence vs. commercial farming. However, in the literature, Borbone (2009) suggests that transgenic crops could help bring about a "doubly green revolution", although a lot of societies still seem to mistrust it. The "Green Revolution", led by Borlaug, Swaminathan and Khush, involved an increase in the use of fertilizers, pesticides and irrigation water with more land for cultivation to increase the production of crop plants especially wheat, rice and maize (Klug *et al.,* 2012). The world's food supply was tripled during the last three decades of the 20th century (Slater *et al*., 2003). However, the green revolution was not really successful in Africa due to drought and problems with infrastructure. Almost 60 years ago, Vavilov (a Russian plant geneticist) suggested that wild relatives of crop plants could be the source of genes to improve agriculture. In science's efforts to meet the needs of society,

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[13]Genetically variable traditional cultivars with sufficient genetic integrity to be morphologically identifiable (Stoskopf, 1993).

Vavilov's vision may be realized, as genes from long-neglected wild crop relatives, identified by new molecular methods spark a revitalized green revolution (Klug *et al.,* 2009) and an increase in agricultural productivity through genetically improved varieties and crop management advances.

The driving forces behind this revitalized green revolution approach are the knowledge, the economic profit and the competing agendas of companies to make money from scientific innovation. However, here again it must be recognised as possibly being exploitative unless it can lead to sustainable living and economic benefits for the communities. According to the data I have collected, as mentioned earlier co-operation between science, society and democracy is fundamental in order to build a knowledge society. According to this study, this co-operation between science, society and democracy particularly applies to biotechnology, as it has a potential impact on people's lives and there is insufficient public and government involvement in issues the participants feel directly involve the quality of their lives. The lack of collaboration between the government, the public and the universities is how criticisms and doubts about biotechnology have arisen in the first place. Discussions are of particular importance when it comes to including IK in biotechnology practices for a knowledge society.

6.3.1.3. Biomimicry

Throughout our existence, humans have looked at nature for answers to problems and this is the basis of indigenous knowledge systems. According to Vincent *et al.* (2006) the term biomimetics was coined by Otto Schmitt, an American academic and inventor, in the 1950s, to describe the transfer of ideas from biology to technology. Biomimicry, biomimetics and bionics are synonymous terms used for the study of nature and the processes in nature so as to apply them in solving human problems (Vincent *et al.,* 2006). Biologically inspired engineering has created new technologies, so one could say that nature has provided the inspiration for solving many of today's engineering problems. Examples include the study of birds in flight to enable human flight in airplanes and improvements in the development of solar cells as a result of studying how plants absorb and utilize solar energy (Margaliot, 2008).

There were quite a few participants in this study who referred to biomimicry as providing solutions which could be used in biotechnology application. One of the responses to the question "What does the word biotechnology mean?" included: ''It means the application of biological organisms/biologically-produced chemicals to solve issues (like biomimicry encouraging different engineering designs)''. Many of the environmental issues that humans struggle with, such as food production, climate control and non-toxic chemistry, even packaging, are naturally accomplished in nature (http://www.asknature.org/article/view/what_is_biomimicry). Biomimicry has economic potential for entrepreneurship by contributing innovative designs and solutions to problems faced by humans. Biomimicry also highlights the importance of maintaining biodiversity. The importance of biomimicry in the context of this study is that it has potential for capacity development and at the same time meeting the need for sustainable development.

Indigenous knowledge and the use of biomimicry could produce African solutions that could build the knowledge based society. However, care should be taken in the way they are included in the biotechnology curriculum. In order for the construction and propagation of this knowledge to lead to economic benefits, and as it is based on indigenous resources, IP must be taken very seriously. In so doing biotechnology programmes at the two universities could make a positive difference and solve problems within local societies and communities.

6.3.2. Worldview perspective of biotechnology

This category of description which encompasses the impact of worldview on the experience of biotechnology will be discussed in relation to the literature with regard to two distinct categories: moral considerations and risk perceptions.

6.3.2.1 Moral considerations

As participants responded to the questions it became apparent that there was often a sense of moral obligation to parents, the community, the environment and the industry of biotechnology because of the knowledge, skills and applications that are associated with this branch of science.

According to the data gathered in this study, knowledge of biotechnology and its application can lead to a moral obligation to do the right thing. This may be linked to carrying what may be considered controversial knowledge back to communities as described by the following participant: “When I first started studying biotechnology I was a little skeptical (sic) about the manipulation of plants for better crop yield. I am of Jewish descent and most of my family does not approve of altering nature. The more I studied it, however, the more I see that ensuring a reduction in famine is far better, morally, than being able to do it and neglecting to do so” [WS16(2010)]. Another point of view was that there was moral obligation to using knowledge associated with biotechnology to improve living conditions and livelihoods as described by the following participant in response to the question of whether biotechnology is valuable: ‘’Yes the fact that it is used to produce better products. I mean, in terms of many disasters that world faces such as hunger, drought etc. Biotechnology e.g. GMOs can be used to solve the problem” [US8(2011)]. The problem with introducing GM food aid into African countries has to do with the fact that the governments of the countries do not fully understand the implication and consequences of GM food and they are wary that the GM plants may kill traditional agriculture. The United Nations FAO director-general urged countries in southern Africa to carefully consider scientific knowledge before rejecting the food aid containing genetically modified organisms when Zimbabwe refused GM food aid in 2002. However, the Lands, Agriculture and Rural Resettlement Minister refused to accept GM food aid indicating that the Zimbabwe population was not going to be used as guinea pigs (http://www.raceandhistory.com/cgi-bin/forum/webbbs_config.pl/noframes/read/993).

There was a general acceptance of biotechnology topics in terms of participants’ community beliefs, especially where it could help by feeding people, as seen in this quote: “I think it is very acceptable. People are starving and I think that if you are able to make a difference in some way that it is your responsibility to make that difference or at least try” [WH1(2010)].

As far as the consideration of religious and cultural beliefs participants in this case study indicated a sense of having a moral obligation to help society, the environment and themselves through biotechnology practices. However, they were concerned about what to share with the community and what would be acceptable in the community because of religious and cultural beliefs. The topic of evolution which comes up in most science and biotechnology topics is not discussed in communities as this is against most religious and cultural beliefs. In biotechnology, evolution theories are even included in topics concerning bacteria, where they evolve over a relatively short amount of time to become resistant to antibiotics. In the case of evolutionary theories, participants practiced cognitive apartheid (Cobern, 1996) and collateral leaning (Jegede, 1995). There were many student participants who did not share such information or explain it to their families or people in their communities.

Furthermore, genetic knowledge can explain things like albinism which is not understood or accepted in different cultural beliefs. The following quote highlights this "[Biotechnology] helps society because it explains what occurred for a child to have albinism. The knowledge will stop the stigma" [WFG2(2012)]. Albinism is widely believed in Africa to be the result of bewitching. According to focus groups the school teachers need to be educated in this respect as the discrimination and mismanagement around albinism starts at school. Penn *et al.* (2010) studied cultural influences on the process of genetic counselling and current conceptions of genetically inherited diseases in South Africa. They found that traditional beliefs were potential barriers to effective genetic counselling. The reason they gave for this was that counselling models follow western contexts and consequently are not that applicable in a South African context which has a rich and diverse ethnic and linguistic profile. Consequently Penn *et al*. advocated for specific interventions based on the country's multicultural heritage and unique disease profile.

According to Herselman (2007), in the African context, people may consult both western and traditional healers in order to improve their chances of recovery from particular illnesses or conditions. It was evident from the focus groups that there were many students who still consult traditional healers because of pressure from parents and grandparents. They are sceptical because of their scientific beliefs but have a moral obligation to follow their families' wishes. Participants explained as follows: "In the communities the traditional healer (Sangoma) is regarded with respect, but still from us learning all this, you question what they put in concoctions. We have open minds, these are respected people in our community – we don't want to step on toes"; " …We just don't take what is given" [WFG3(2011)]. Jegede (1997) states that in the African mode of thought the elders repository of knowledge is truth not to be challenged and the respect demonstrated by participants for this is evident in the outcomes of this research. Elders hold positions of great respect within the community and the family in African cultures (Kasanga and Lwanga–Lumu 2007). However, participant responses to this knowledge of the elders are changing, and they are becoming tentative and challenging. Out of respect for the elders, student participants are hesitant to share certain concepts with their community, such as that DNA and genes are transmitted from one generation to the next. What is interesting to note is the contradiction or ambivalence that is evident here, because the participants are showing rejection of traditional practices and knowledge, such as that held by traditional healers. At the same time traditional values of respect for the elders is very strong.

In the African culture, grandparents have always played a central role in relation to teaching and bringing up children. According to Forrest *et al.* (2003), they serve as gatekeepers of knowledge about illness and treatments. Liddell *et al*. (2006, p219) suggested that "the construction and implementation of illness representations are firmly grounded in culture and socialization", whether social or cognitive in origin. As a result of the HIV/AIDS epidemic the roles and responsibilities of grandparents have increased as they have assumed the role of primary caregivers due to the death of a large number of the middle generation, i.e. their children/the parents of their grandchildren. According to Barratt and Penn (2009) grandmothers are often left in leadership positions within communities as men relocate to the cities in search of work. In the study by Penn *et al.* (2010) it was shown that grandmothers believed that conditions actually related to genetic disorders were caused by: (1) **lifestyle**, i.e. eating culturally forbidden foods during pregnancy; wearing tight clothing during pregnancy or promiscuity (2) **behaviour** i.e. laughing at someone with a disorder or visiting the zoo, as one must not be frightened by anything (3) **social** causes such as abuse and domestic violence (4) **familial** causes such as consanguinity (5) **cultural** i.e. not following cultural rituals and (6) **religious** i.e. punishment from the ancestors or alternatively, could be a gift or punishment from God. However, some causes given by the grandmothers for example, Downs syndrome being related to advanced maternal age, provides evidence for Stanley and Brickhouse' (2000, p46) argument that "WMS has borrowed ideas and technologies from all over the world. Similarly, indigenous people have often selected particular aspects of WMS that they find useful". Although IK (and TEK) are regarded as different from WMS it is important to understand that the traditional views as represented by grandmothers' beliefs are rooted in cultural assumptions. In the development of a knowledge-based society in which IK is becoming more and more important it is essential that curricula present opportunities to engage with various forms of knowledge.

The tension between socio-cultural/religious beliefs and scientific explanations is apparent in situations such as the issue of consanguineous marriage. In terms of genetics, consanguineous marriage is discouraged. However, in certain cultures such as Hindu and Tamil, consanguineous marriages are actually encouraged: "We are also allowed to marry a cousin which is something that is not encouraged in genetics (science). ….In my Islamic family we have many married cousins" [WFG3(2012)]. Cultural obligations, for example in terms of arranged marriages, create a moral dilemma for students who have learned genetic concepts. One of the participants explained: "In a recent consanguineous Islamic marriage the first born son has deafness. I explained to my cousin this could be because they are cousins because I understand this. She is sceptical but she is worried about having more children and how they can be affected. Genetic Counsellors have explained this and I have with my acquired genetics knowledge" [WFG3(2012)]. Here, the student is the culture broker for the community, and the moral obligation that is felt to inform the family to improve lifestyle, and solve problems, is evident.

6.3.2.2. Risk perceptions

The potential abuse of techniques developed in biotechnology could lead to harm, for example the use of bacteria for biological warfare, is an issue of great concern. This was raised in a study by Massarani & de Castro Moreira (2005) and by the participants in my study. Participants in this study also strongly suggest that the release of biocontrol agents and mycopesticides into the environment should be tightly controlled and regulated and field trials should assess for potential harm. These concerns are addressed by laws such as the laws instituted for biosafety i.e. the Cartagena Protocol on Biosafety (http://www.iisd.org/pdf/biosafety.pdf). The biosafety laws protect scientists and the environment. These laws on GM are also required for the rational, logical and scientific management of GM activities. They protect people and those not interested in biotechnology as well. However, there is the political side. The South African and

Namibian participant stance in this matter is that governments' GM policies should be rational and progressive. The South African DST's plan to become a world leader in biotechnology based on indigenous resources is inspirational and progressive, but at the same time could be harmful, in that we need to protect our biodiversity and maintain it, so there is a fine balance between becoming a world leader in biotechnology and protecting our communities where the knowledge has originated. Risk perceptions provide a platform for people to discuss the benefits and problems of biotechnology, and emphasize the need for well-informed public debate.

6.4. Biotechnology Tertiary Education

The Relevance of Science Education (ROSE) project (Sjoberg and Schreiner, 2005) involving more than 40 countries investigated school science and found that in all participating developed countries, school science was less popular than other subjects. There was a diminishing interest in school science as there was a lack of discussion of topics of interest, absence of creative expression, no opportunities, and the alienation of science for society. Research by Tytler *et al*. (2008) suggested that the more developed a society is, the more students liked other subjects over science. However despite these observations biotechnology at WITS and UNAM are fully subscribed. One of the issues also raised by Tytler *et al.* is that science is "alienated" from society. In the case of biotechnology the connection between science and society is evident. However, the experience at WITS and UNAM has been that students become aware of biotechnology through an initial engagement with biology. Many are students who failed to meet the admissions requirements for medicine so by default they turn to a BSc with the hope getting into medicine later. Once enrolled in a BSc they then become interested in biotechnology through interaction with lecturers and teaching assistants and they see career opportunities in biotechnology.

Student participants indicated that the topics were exciting with opportunities not realized before, for example with regard to the medical research field including drug discovery, helping the environment and food production for the increasing population.

According to Tanase and Wang (2010) beliefs about teaching and learning are often idealistic. These beliefs are based on upbringing, school experiences, ethnic, cultural and social backgrounds. In their study, Tanase and Wang found that there is a change in epistemological beliefs of student teachers from the beginning of a new course to the end of the course. This, according to them, is analogous to how learners develop in school careers. This shift in epistemological beliefs was also found with regard to both the lecturer and student participants in my study. These epistemological beliefs are multidimensional and a change in them is possible through the sequential process described by Perry (1981) (Discussed in the literature review). The following quotes are evidence of this: "Hard to believe concepts first time hear about them – becomes clear and believable with understanding" [WS10(2010)] and "Learning biotechnology for me was (and it still is) a big challenge for me (sic). Especially in the classroom where we got introduced to a wide range of new ideas that we have never come across. But with the help of study groups with fellow students, I actually managed to get comftable (sic) with learning biotechnology" [US35(2011)]. From this it can be seen that the curriculum needs to be constructed in such a way that students are exposed to ideas so they are able to do the border crossing into science. When students go through a sequential development in their epistemological beliefs as theorized by Perry (1970) and Magolda (1996) and Khun *et al.* (2000), their beliefs of 'Absolute knowing' can be replaced by 'transitional knowing' and often 'independent knowing'.

From my study it is evident that epistemological beliefs can be challenged and transformed through teaching and learning. Awareness of the epistemological beliefs of the participants is critical in the development of a biotechnology curriculum that would then assist with capacity development in southern Africa. The pedagogical imperative inherent in the outcome space can usefully inform the T&L of biotechnology through the design of a relevant and sensitive curriculum.

6.4.1. Recommendations to inform the biotechnology curriculum

Having established the sensitive nature of the experience of biotechnology, it follows that in the context of this study, the biotechnology curriculum needs to be developed to enrich student knowledge from both an indigenous knowledge (IK) and a science knowledge (SK) point of view. This will assist in providing the epistemological access that has been called for students in universities in southern Africa. According to Morrow (2009, p78) "…epistemological access is learning to become a successful participant in an academic practice", by successfully achieving epistemological access the student is linked "into a trans-cultural community", and can relate "to the ideals of human emancipation that we inherit from Enlightenment" (Ibid., p84).

It has become clear in education that there has to be a balance between globalization and local contexts, especially since diversity and identity are recurring themes about the impact of globalization on education (Lederman 1992). According to Banks (2008, p132), multicultural democratic nations (where school populations have become more culturally, racially, ethnically, and linguistically diverse because of immigration) struggle with a number of significant issues, such as language rights for minority groups, paradigms, and ideologies. Another issue in the debate around globalization and education is the question of fragmentation (Lederman, 1992). Fragmentation refers to efforts to maintain the traditional independence of social groups in solving key issues (Milašinović and Bajagić, 2005). In the same view, McKenna (2012, p18) has warned that western knowledge could be regarded as a new form of 'colonialism' which could negatively impact the development of knowledge in home countries.

In the context of the above, curricula should be inclusive of IK and should facilitate thinking around global pressures and ideologies in the light of what is important in communities, and how tertiary education programmes should inform capacity development.

As summarized in chapter 5, Table 5.4 and Section 5.6.2., the outcome space of the empirical investigation has a pedagogical imperative where the response that resulted was to provide for epistemological access in the development of a biotechnology curriculum. This result supports a pedagogical imperative to promote awareness of teaching and learning in biotechnology that focuses on the application of worldview theory, which includes the theories of collateral learning and learning through cultural border crossing. Consequently, the progression in the complexity of the experience of biotechnology has an effect on the development or not of border crossing and collateral learning. Also the approach to T&L that allows for epsitemological access in the theoretical and practical category includes constructivism, where new knowledge is built on prior knowledge with awareness of the social and cultural aspects of knowledge that could be related to the courses being taught. With a techno-epistemology association the courses should be relevant to the African environment with the aim of providing African solutions for Africa. The approach to T&L in the worldview category supports a socio-cultural constructivist approach, so that there is acknowledgement of traditional, cultural and religious beliefs and an awareness of the socio-cultural background of the students.

Further recommendations to inform the development of a biotechnology curriculum are presented in the following sections. The first section deals with the experience of the biotechnology curriculum with recommendations for ensuring epistemological access. The second section deals with cultural border crossing and collateral learning and then finally, the third section is concerned with the successful implementation of cross-border tertiary education that is relevant in the African context.

6.4.1.1. Biotechnology teaching and learning and epistemological access

According to Opie (2004) epistemology and epistemological questions and issues are of important concern in education research. The research questions posed in this study required an investigation of teacher and learner epistemologies of biotechnology at the two SADC universities involved.

Perry (1981) suggested that there is a sequential development of epistemological beliefs. The epistemological beliefs range from absolute knowing, transitional knowing, independent knowing and contextual knowing (Tanase and Wang, 2010, p1239) as is discussed in the literature review. Tanase and Wang (2010) building on Perry's work posit that this epistemological sequence development involves the construction of knowledge, the facilitation of the construction of knowledge and the nature and validity of the knowledge.

Contributions by Morrow (2009) which assist in how to approach the development of knowledge for epistemological access include his ideas on higher knowledge and grammar. He claims that it is in the area of epistemology that the practical and the intellectual value of higher knowledge is fully apparent. The kind of knowledge that is a potential and potent catalyst for innovation and growth is called 'higher knowledge' (Morrow, 2009, p117). Morrow claims ‘higher knowledge’ is the “kind of knowledge which is of special concern in Higher Education [which] builds on an already achieved mastery of more elementary kinds of knowledge”. He goes on to argue that higher knowledge is “in the background of discourses claiming that modern societies are ‘learning’ or ‘knowledge’ societies” (p117). Morrow (2009, p38) further argues that in Higher Education certain practices have their own grammar and if one understands the constitutive grammar of a practice then that is higher knowledge.

In terms of this study then, students with an understanding of the grammar of biotechnology should then have a higher knowledge of biotechnology which is an indication of having appropriated the discourse. Morrow goes on to argue that higher knowledge entails developing a capacity for creative and critical reflection by building on prior knowledge. This capacity for creative and critical thinking leads to different levels of reasoning where the student has a particular understanding (Ibid.).

There is evidence from the participant responses that using prior knowledge as the basis for learning biotechnology makes understanding the concepts more meaningful. Thus the inclusion of non-western forms of thought with basic biotechnology practices facilitates the development of ‘grammar’ and ‘higher knowledge’. What is being described here is constructivist pedagogy, which includes support for integrating traditional i.e. IK systems into educational institutions. In this regard, constructivism should be considered to be applied as a pedagogical approach. According to Jones and Brader-Araje (2002) in regard to using constructivism as an approach, social constructivism (Vygotstky, 1978) and education constructivism (Matthews, 1998) have had the greatest impact on instruction and curriculum design. Constructivism is appealing to educators because it places importance on making meaning and on the active role of the learner (Jones and Brader-Araje, 2002). In this approach the lecturer is aware of prior knowledge, beliefs and experiences of the student and these are taken into consideration. By building on this prior knowledge and experience the student learns by constructing new knowledge. The cognitive conflict that emerged in the outcome space in this study is even considered constructive to learning according to Jones and Brader-Araje, who mention eliciting cognitive conflict as one of the practices included in constructivism that helps build understanding. Vygotsky (1978) laid the foundations for social constructivism in education. His theories emphasize the role of the community and the role of significant others in learning (Jones and Brader-Araje, 2002). In education, cooperative and collaborative teaching strategies emphasize the practice of social constructivism, and Jones and Brader-Araje (2002) argue that in both of these the emphasis is on students working together, sharing ideas and challenging each other's ideas.

This study has shown that the initial six categories of description that emerged as shown in Table 5.2 are the different ways of experiencing or understanding biotechnology that are present among the people who teach and study the subject and they need to be addressed and challenged in curriculum design.

The concepts that are highlighted in bold letters below are those that emerged, in this study, from the students and lecturer conceptions of biotechnology teaching and learning. These conceptions are key issues and are what emerged as the common points identified as leading to good T&L practice. These include (a) on the theoretical side: approachable lecturer attitudes, teaching approach i.e. the way the information is presented, and information on career opportunities; and (b) on the practical side: practical laboratories, field trips (industrial component and everyday examples), and finally information regarding the business aspect of biotechnology.

It was evident from participant responses to questions such as "Can you approach your lecturer if something is worrying you about the content or action of biotechnology?" and "Describe your biotechnology learning experience" that **lecturer attitudes and the teaching approach** emerged as important in playing a role as to whether learning takes place or not. Kidman's research study (2010) supports this view by saying that teacher attitudes have an effect on science classroom practice in general. However, she adds that the extent is not known in relation to biotechnology. Lecturers at both UNAM and WITS state that they are confident of their T&L practices when teaching biotechnology. However the student participants highlighted the following characteristics as being important in the biotechnology teaching and learning environment. Firstly, the lecturers should be **approachable** concerning the content or action of biotechnology, so that the students can learn and build their knowledge. When lecturers are approachable students feel comfortable to discuss any issues relating to the content and work that they have. This is important in facilitating learning. Secondly**, the way the information is presented** is very important, as it affects whether the students learn or "shut down". In response to the question "what are the special considerations that you think need to be taken into account in teaching biotechnology?" one of the participant lecturers explained his practice as follows: "…Take precautions and present the information so that the students do not associate it with playing God. The two are not connected" [UL5(2011)]. Furthermore, certain concepts must be very carefully explained and issues must be clarified, as suggested by the following: "Yes if you are teaching you realize very quickly there are students with issues/problems with the technology - some people with specific problems i.e. the switching of genes between organisms" [UL5(2011)].

In this study, the students provided evidence concerning key ideas of interest which were topics that included hands-on modern biotechnology practices (such as seen in contemporary television programmes such as CSI) together with topics associated with **career opportunities.** This is confirmed in the literature where for example the OECD 2003 Forum found that students prefer to study topics relevant to society and to their world, which include with aspects of real-life and cutting-edge science and technology. Furthermore the hands-on practical laboratories should typically advance the understanding and the use of language, such as the grammar of the biotechnology practice thereby leading to the generation of higher knowledge (Morrow, 2009). Kidman (2010, p369) urges teachers and curriculum designers to determine student interests and to relate these interests to subject matter to provide a base for new knowledge. Studies have shown "that a better fit between curriculum and students' interests could lead to better cognitive and effective outcomes in the sciences", and furthermore, according to Trumper (2006) an increase in science enrolments. Booth (1997) argues that teaching tasks that have personal meaning for the learner and that are integrated into the world that the learners' experience is one of the principles for teaching implied by phenomenographic research.

The data collected from the student and lecturer participants highlight the importance of **practical laboratories for visualizing and observing** what was learnt in the theory by making the connection between what is abstract and what is concrete. Practical laboratories give students the opportunity to do hands-on experiments and to interact with the concepts which helps with understanding, and they provide the evidence that supports what they find in the textbooks. Practical laboratories are also important for skills development. However, at UNAM there are not always practical laboratories for all biotechnology courses due to a lack of resources such as equipment and necessary chemicals. Practical laboratories are certainly recommended by all involved in biotechnology courses, and as they are lacking at UNAM, simulations and video conferencing (which could be afforded through cross border teaching and learning) are recommended.

Participants recommended that practical laboratories should further be supported by essays, presentations and practical laboratory scientific reports. Essays and reports were all highly rated as helping students understand and internalize the concepts. The participants also indicated that by remaining aware of the socio-scientific nature and ethical considerations of biotechnology and the cultural context biotechnology can play within contemporary society would help in their learning.

Field trips were also recommended by all participants. These can directly give the students ideas as to career opportunities, which is something they are always interested in. According to Kidman (2010, p355) “the untested hypothesis is that the more that is known about students’ and teachers’ biotechnology interests (within a biological context) the more feasible it will be to develop biology curricula that will engage the students’ attention for learning and the teachers’ attention for pedagogical excellence.”

Further recommendations included adding an **industrial component** such as industrial visits to courses i.e. field trips together with situations where students work in the industry to give them the opportunity to practice the research and to work with the equipment used in biotechnology research. Students with the industrial experience are more likely to adapt quickly to the working environment. The background concerns to developing a relevant curriculum for Africa was that the university needed to do more to make the students employable and with an industrial component this could be accomplished together with encouraging students to be independent.

Participants referred to the need for biotechnology courses to provide a **business aspect** because biotechnology is geared for commercialization. It is important that students can get to the point of proof of concept of products for commercialization. As the government itself is turning to the development of a sustainable economy, students especially those from rural communities should be encouraged to start businesses using the knowledge they learn in their biotechnology courses. "The students who come from the rural areas may be scared of the commercial side. However, once they come to tertiary institutions they actually grow up quite fast and a lot of them want to become entrepreneurs. And they've got fabulous ideas, but it's taking that risk to venture into business. I came across an organization in downtown Jhb called The Hub, and they do exactly that, they encourage young people who have a business idea to come in and meet other people and they have business seminars and they learn about entrepreneurship. I think that's something we need to do something like that within the university. This would encourage undergraduates to start their own businesses......" [WL6(2012)]. The emphasis on transformation for economic advancement has influenced lecturer participants at both WITS and UNAM and they are very enthusiastic as to encouraging students to develop entrepreneurial skills. According to Shore (2010), this entrepreneurialism in turning intellectual property into marketable commodities is also encouraged at the University of Auckland, New Zealand.

The issues that have been raised in this section point to the need for African solutions to African problems. This includes the need for WITS and UNAM to identify themselves as African universities, with regional outputs which benefit local communities. If these universities could train rural communities in the practices of biotechnology for sustainable development this could lead to a sustainable economy. Morrow (2009) argues that we should not forget that Africa has its own alternative forms of knowledge together with its own economic and political reasons as to how to conduct itself. With this in mind, courses can be developed that will more actively enable epistemological access thereby supporting society and government through the development of the knowledge economy.

The physical locations of each university in this study, together with the market forces in their areas, have driven the development of their research foci. WITS have an industrial, agricultural and environmental biotechnology focus and UNAM have an agricultural and environmental biology focus. However, when integrating IK systems into educational institutions, it should be kept in mind that market-driven misdirection of research could ruin the sustainability of the indigenous resources. In this respect, researchers at the relevant universities would need to find the balance between the use of IK and science knowledge to allow it to be sustainable.

6.4.1.2. Cultural border crossing and collateral learning

Collateral learning and cultural border crossing are cognitively based theories of learning which can serve in a practical sense as a response to what the phenomenographic analysis produced with regard to how participants respond to the phenomenon “biotechnology”. Cultural border crossing and collateral learning can be tools for forming curriculum statements and devising pedagogical activities to support epistemological access. In the outcome space, the hierarchy of categories constitute a progression that involves an increase in the sense made of biotechnology theory and practice, and in the degree of how students move between everyday life worlds and the world of science. Collateral learning (Jegede, 1995) and cultural border crossing (Aikenhead, 1996) explain how they deal with the cognitive conflicts that may arise between the two worlds.

Barner (2011) supports the importance of both culture and belief in reference to a meaningful learning experience in science. He argues that science education should not be about the marginalization or abandonment of one culture in favour of the other. This view is supported by Jegede (1997) who says that when science is learned by people with a traditional worldview their cultural attitudes and local knowledge about their environment should be included. This he argues would help to develop a scientific culture. The existence of boundaries based upon philosophical and worldview differences was demonstrated by participants in this study, as biotechnology was sometimes described as a “whole new world” by participants, and biotechnology concepts were described as being foreign and difficult to understand. Examples included participants referring to entities that were not visible to the naked eye; fungi having biotechnological applications; and the use of words such as “primer” which describes a piece of DNA used to produce a cloned sequence in the polymerase chain reaction. Such examples serve to illustrate the differences between the students’ life-world experience and the discipline of science, confirming that in biotechnology, as in other disciplines of science, learning science is a cross-cultural experience for many students.

The “border crossing” from the subculture of their communities and families into the “subculture of science” (Aikenhead, 1996) is evident in participant responses when dealing with the biotechnological aspects of fungi which have many biotechnological applications in the industrial and the food industry. However, here is an example of the lecturer, acting as a “culture broker”: “Fungi with Prof X! I answered a lot of questions that he asked and he made me see the reality of the world from a different angle” [WS30(2011)]. In other cases participants preferred to use parallel collateral learning when it came to fungi, because for religious reasons fungi were seen as a living organism and should not be eaten or genetically manipulated, thus never resolving the conflict between the two beliefs, as in parallel collateral learning. The evidence of this is in the following quotes: “I come from an Islamic home which is a Muslim background. I think scientific beliefs especially genetic beliefs are accepted within the bounds of our laws but evolution is not acceptable at all” [WFG3(2012)].

It has also emerged through the research process that some participants have moved to what Jegede (1997) described as “dependent collateral learning” where when students became aware of scientific explanations, their prior beliefs would be forced to be considered in relation to them. For some students the exposure to new knowledge led to changes in understanding, as described by one of the participants: “My movement into critical thinking, ergo science removed all prior ‘belief” into non-rational entities and thought processes. I accept evidence only, and am willing to change any belief where new evidence comes to light” [WS21(2011)]. In some cases it was repeated exposure that led to acceptance: “In my first encounter with the course it was hard to believe because it was my first time hearing about, but after a month of been (sic) taught things became clear and believable” [WS10(2010)]. For many participants it was the weight of evidence from the peer-reviewed scientific literature, and in the empirical evidence when the proof was performed in practical laboratories, together with the practical evidence in everyday life that resulted in border crossing. The need for concrete evidence to assist in understanding is highlighted in the following: “Some concepts yes but others are too complex to actually believe without seeing them in real-life or practically” [US35(2011)].

These examples where the "troublesome knowledge"[14], which includes difficult concepts to understand for various reasons such as being abstract or counter-intuitive because of worldview, is grasped in a practical laboratory when the empirical and visible evidence helped with understanding and acceptance. This acceptance equates to a threshold concept which according to Meyer and Land (2003, p1) is equivalent to a portal, "opening up a new and previously inaccessible way of thinking about something". According to these authors a learner cannot progress without this new way of understanding or interpreting. Because of the multicultural nature of the participants in the case study, including indigenous knowledge will also increase the relevance of what they are learning for the students, thus making it more interesting and leading to learning. That the use of examples of indigenous science has resulted in an increased interest and participation by African learners has been shown in a number of studies (Brown *et al*., 2006).

Participants described a sense of power or superiority associated with the practice and knowledge of biotechnology. The following quote captures this and highlights the "passage of power" which participants saw as being associated with their growing knowledge: "At least now we know we'll get jobs that are important, very important" [US12(2009)]. This recognition assisted the process of border crossing as participants become convinced by the prospects associated with biotechnology. However, biotechnology knowledge in some cases encourages collateral learning where the students construct western and traditional knowledge side-by-side. Jegede (1997) suggests that the African can effectively absorb and use scientific culture in everyday life without it impacting or shifting their worldview beliefs.

A project called Public Understanding of Science (PUS) (The Royal Society, The Public Understanding of Science, 1985, in http://royalsociety.org/displaypagedoc.asp?id=26406) was undertaken in England to investigate whether greater scientific literacy would correspond to greater acceptance of science, but the outcome contradicted this. It was shown that tension

[14] Perkins (1999) described troublesome knowledge as knowledge that is conceptually difficult, counter-intuitive or 'alien' (cited in Meyer and Land, 2003)

arose because society does not always accept scientific concepts, even though it does not want to give up the benefits of science.

According to responses during the interviews, to the questionnaires and during the focus groups conducted there is a lot of buy-in and “hunger” for the knowledge that biotechnology produces. This brings about a shift in worldview presuppositions as students are exposed to biotechnology courses and as a result changing social situations. The lecturers and most of the student participants felt very strongly that biotechnology techniques could improve living situations. Consequently students would take back the information to their communities and in this way “culture brokering“ was happening at a number of levels: lecturers acted as culture brokers to students, other students (their peers) acted as culture brokers to students, and the students were culture brokers to their parents and to the community. The appeal of the use of biotechnology techniques to improve living conditions seems to have provided the impetus for students to cross into the world of biotechnology. The importance of study groups, where peers are able to create a zone of proximal development (Vygostky, 1978) is illustrated by the following comment: “But with the help of study groups with fellow students, I actually managed to get comftable (sic) with learning biotechnology”. Here it appears to be the fact that other students “believed” the information and were able to explain it seemed to facilitate epistemological access.

In terms of communities, students have faith in the fact that their communities will accept the ideas and practices of biotechnology if it comes from them because they are respected in bringing the knowledge from universities. In this way there is a dissemination of knowledge back to the communities, and a gradual shift in understanding and acceptance of science, potentially making the question of epistemological access in this field more easily accomplished.

6.4.1.3. Cross-border Teaching and Learning

The SANTED project resulted in the introduction of biotechnology courses at UNAM, and the growth of interest in regional cooperation through cross-border teaching and collaboration between WITS and UNAM. A cross-border T&L programme in southern Africa will allow the effective use of existing expertise which is in accordance of the SADC protocol on education (as discussed in Chapter 1).

From the data collected in this study, there is considerable buy-in for a biotechnology cross-border programme in southern Africa, as is supported in the following lecturer participant quote: “I would like to know if the SANTED programme is going to be revived/starting up again? We want to get to the point of informing cross-border teaching and learning in biotechnology and inform the curriculum” [UL2(2011)]. Cross-border programmes between African countries supports the idea of being able to share and face problems on the African continent together, as is supported by the subtext of the following student participant quote: “…I think it would be better if countries combine ideas, because we all have similar situations /problems and we also have indigenous methods that we can share….” [WS20(2011)]. The importance of this research study showed worldview differences, but this data, especially with respect to IK, extends the generalizability of the findings in the SADC region because of participant reactions in which cross-border teaching and learning is valued.

The ideas mentioned above, are in keeping with SADC objectives and internationalization where collaboration and academic enterprise are encouraged through cross-border sharing and teaching. Thus it appears that regions and communities can be strengthened through cross-border biotechnology programmes because of the opportunity for collaboration and sharing.

6.5. Methodological findings, limitations and further recommendations for future research

6.5.1. Methodological findings

Phenomenography enabled the emergence of the categories of description which highlighted sensitivities related to biotechnology. Recommendations for pedagogic practice also emerged in the outcome space as the features distinguishing the different categories from each other were the basis for informing teaching and learning practice for epistemological access.

With respect to the instruments used to collect the data, the interviews with the lecturer participants created a space for them to think about and reflect on their own T&L practices. I found that they had spent time thinking about their knowledge and understanding of biotechnology, and had also spent time reflecting on how they should respond to the ideas and concepts of biotechnology. A quote to support this includes: “I enjoyed thinking about and developing my own philosophy through answering your questions” [WL3(2010)].

In Morrow’s book, “Bounds of Democracy” (2009) which explains his concepts of epistemological access, he advises that we focus on the educative practice of discussion, as only some kinds of curriculum change represent an improvement if they are grounded in epistemic values. Humans relate to each other through discussion when they share their feelings and emotions. Our opinions are sometimes transformed through discussion. The interviews and focus groups had this effect: students were willing to discuss their ideas and concerns which allowed issues of epistemology to emerge in the analysis.

Although lecturers and students have different roles in terms of the teaching and learning of biotechnology they did not appear to be saying significantly different things. This is the reason I analysed the lecturer and student transcripts together. However, what was significantly changed through the research process was my own perspective, especially with regard to the different levels of complexity of experiencing biotechnology and the ethics involved. As described above, lecturers interviewed also found their perspectives on biotechnology T&L challenged. These findings have important implications for the approach to instruction by the lecturers. Stanley and Brickhouse (2000, p44) have argued that “Universalists and multiculturalists would likely approach instruction in significantly different ways”. My experience through this research study was to move from a Universalist to a multiculturalist perspective. The significance of epistemological access has helped me to become aware of the need to avoid cultural domination and hegemony.

Engagement with phenomenography and the iterative process was very valuable in forcing me to find out how people respond to biotechnology. In the process of analysis, the emergence finally of two broad categories was exciting and has potential for convincing Universalist lecturers to consider the impact of worldview on teaching and learning.

6.5.2. Limitations

In trying to understand what could limit the trustworthiness of this research, three areas immediately became apparent. The first relates to my positionality. My personal interpretation is embedded in the understanding that is brought to the analysis because of my cultural background, history and experiences. Some of my assumptions could be so deeply embedded that I am unaware of them and if I am aware of them it has not occurred to me to question them. Furthermore, my background knowledge differs from that of the participants in the research sample, just as the participants in the research sample differ from one another: socio-cultural background, religion, education, health, and genetic makeup all play a role in affecting how we react. However, at all times the analysis was applied as objectively as possible and all criteria for trustworthiness as discussed in chapter 4, section 4.8, were addressed to limit both personal and methodological biases.

The second limitation has to do with how I interpreted the data. This research is of a contemporary phenomenon within its real-life context and it has enabled the analysis of the "how" and the "why" of the need for an African biotechnology curriculum. My own immersion in the discipline could have biased how I went about developing the categories of description. This could also have affected how I envisaged appropriate teaching and learning strategies. In order to reduce this bias a coder reliability check was performed as described in Chapter4.

The third limitation relates to the research instruments. The questions asked in the interviews, questionnaires and focus groups could be seen as a limitation to the study. The way questions are asked, limits the response, i.e. if questions had been asked slightly differently, the responses would be slightly different. However, the questions which formed the substance of the questionnaires, interviews and focus groups facilitated sufficiently appropriate responses in terms of the research questions that shaped the study. Data collection was triangulated in order that saturation could be reached and indeed finally saturation in the answers was reached with nothing new regarding biotechnology experience emerging.

6.5.3. Further recommendations for future research

This research study has confirmed that, in the context of the study, there are worldview issues at stake in the teaching and learning of biotechnology. This is the "niche" of the case study and the new knowledge that it is contributing. This research has served to investigate the question of the impact of culture and the issue of epistemological access in biotechnology teaching and learning. The data has shown that for some students, cultural border crossing is required for successful learning. In some cases students are collateral learners or they practice cognitive apartheid, but at the same time the science of biotechnology is embraced.

The methodology of phenomenography has allowed for a rich engagement with the data, and for future work the next step would be to construct a curriculum that specifically takes into account the recommendation to provide epistemological access. Once such a curriculum has been conceived and implemented it should be followed up by an investigation to assess its success in this regard.

Furthermore, cross-border teaching between the two Universities was embraced by all participants involved, so it is something that needs to be considered and planned in more detail from a financial and logistical viewpoint.

6.6. Conclusion

The research method, phenomenography, used in this study is a unique and empirical qualitative research approach which has enabled me to answer the research questions in a way that has practical and useful implications for pedagogy. This approach has allowed a rich engagement with the data, and it has added to the body of knowledge of how and what the experience of the phenomenon "biotechnology" was for the sample group in the case study. The initial six categories of description that emerged described the experience of biotechnology by the lecturer and student participants. All six of these categories should play an important role when considering the development of the biotechnology curriculum for epistemological access. Thus this research, which has been the first to interrogate biotechnology teaching and learning in southern Africa, has made a unique contribution to the field of biotechnology tertiary education in the SADC region. As a product of the enterprise of western modern science, biotechnology is taught at present through curricula that have not been modified according to local context. From this study it is evident that prior knowledge and worldview are critical to students' ability to understand and learn the material they are presented with. In the context of southern Africa, where there are many different 'ways of knowing', the need to provide epistemological access to all students is critical, especially in situations where cultural perspectives may be in conflict with the epistemology of western science. This new field of research has highlighted where potential cognitive and epistemological conflicts may arise. These conflicts provide barriers to learning, which can be avoided by a change in curriculum and in the attitude of the lecturers. Their attitude can in turn reduce student drop-out and aid meaningful learning by enabling access to the knowledge of biotechnology.

Key issues in Higher Education are in the areas of student access, retention and success (AR&S), and multilingualism. It is in all our interests that students succeed. However, with the reality of more students entering our tertiary institutions as is evident at both WITS and UNAM, there is an increase in demand on financial and human resources. Many are first generation students, often needing financial aid, extra tutoring, and social and cultural guidance to make it. Furthermore, UNAM need more laboratory and teaching resources, which could be attained through a cross-border teaching programme. The point made by this study is that a revised "African" curriculum could lead to improved student success and retention in our universities.

This investigation found indigenous knowledge and practices overlap with the field of biotechnology, and because of this it is important to enable epistemological access to the biotechnology curriculum. In this research study examples have provided evidence that illustrate the relevance of universities supporting research within their communities, and of the use of IKS in the biotechnology curriculum in response to building the knowledge based economy. There is also empirical evidence of turning intellectual property into marketable commodities. Thus supporting the imperative for universities to become involved in capacity development and it meets the CHE's (2007) transformation agenda for universities to respond to the needs of society.

This research has not only produced new knowledge, but if the recommendations are considered it will have a very important and practical application in the field of biotechnology curriculum development in southern Africa for capacity development.

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Appendix A

Table 1 showing the alignment of questionnaire and interview questions with research questions

Research questions	Interview questions for teachers
Research question 1 What worldview concerns might be contained in the biotechnology curriculum? Research question 2 How do these worldview concerns affect epistemological access to the biotechnology curriculum?	What does the word biotechnology mean to you? Describe your biotechnology learning experience/ background. How do you know when you really understand the information? Who or what motivated you to learn biotechnology? Why do you want to teach biotechnology subjects? How do you encourage high-level thinking, in other words, how do you get the students to apply their knowledge? What sort of assessment do you think helps the students deal with the content (formative vs summative assessment/ practical tests/ questionaires/ no summative assessment) Do you find out what students already know or have experienced? How do you use this in your teaching? What would be the purpose of you

	referring to what students already know? What areas do the students struggle with most to understand? Why? What are your views on GM foods – do you use GM foods for your own families? Do you know if the foods you buy are GM? What do you think of the govt's stance on GM? Do you agree with the govt's laws? Why do you think they have been instituted? Do you know of any beliefs that make 'messing with genes' unacceptable or dangerous? Do any biotechnology practices make you uncomfortable? If they do, why? What is going on? How are practical laboratories useful in your teaching curriculum?

Research questions	Interview questions for students
Research question 1 What worldview concerns might be contained in the biotechnology curriculum? Research question 2 How do these worldview concerns affect epistemological access to the biotechnology curriculum?	What does the word biotechnology mean to you? Who or what motivated you to learn biotechnology and why? (This can be anyone or anything or an event in your life) Describe your biotechnology learning experience. This can be in the classroom or just a general experience outside of the classroom. Describe a class room situation where you felt you were really learning to do biotechnology. How do you know when you really understand the information you have learnt in the class? Which of the biotechnology courses you have done have you enjoyed the most and why? How does your lecturer encourage you to learn? Can you approach them if something is worrying you re content? How believable to you is what you are learning? How acceptable to you is what you are learning in terms of your communities' cultural beliefs? Please explain. How do you value biotechnology knowledge? What value does this knowledge have for you? What are the benefits of biotech? Do the benefits outweigh potential harm? Is there any information / practices you are learning that you would hesitate to tell your grandmother about because it might

	be offensive to her way of understanding the world? How do you use all your prior knowledge during the lectures? (this can be from school, university or just what you already know and have learnt at home) What sort of lecture styles are you most comfortable with? Do you think practical laboratories help you understand the concepts better? What sorts of assessments help you understand the concepts and the content best?
Research question 3 How can the outcomes from questions 1 and 2 inform the biotechnology curriculum?	What do you find most difficult? (volume of work, foreigness of ideas, …) In your opinion, what is good or effective biotechnology teaching like? What kinds of teaching and learning methods do you consider good for teaching biotechnology? What are the characteristics of biotechnology that motivate you to teach it? Do you think that biotechnology has a multidisciplinary training potential? What biotechnology subjects are important for students to learn especially with regard to the economy in your country?

	In what way does the new programme design conform to your institution's mission statement? In what way does the new programme design meet the needs of the students? What parts of the new design complement your Teaching and Learning methods? What is your academic profile i.e. what is your background at university? What is your library infrastructure and resources like; i.e. IT infrastructure, training and staff and student accessibility?

Other information needed will also be included, for example, the topic involved, the number of students, home language and gender.

Appendix B

Invitation to participate and information sheet

School of Molecular and Cell Biology, University of the Witwatersrand,

Private Bag 3, WITS 2050, South Africa

Mrs Jean Mollett

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Fax +27 11 717 6351

I hereby invite you to take part in the very valuable research described below.

The title of this research is: Tertiary Education Capacity Development in Biotechnology in the Southern African Development Community (SADC).

It is envisaged that biotechnology can play an important role in addressing critical problems in areas such as crop agriculture, animal and human health, food security and environmental sustainability in southern Africa. The skills required to establish biotechnology knowledge come through capacity training at tertiary institutions. We as lecturers and learners in this field are at the forefront/coal face of this capacity development in tertiary education in our countries.

This research, which will involve your views on biotechnology, began because of my involvement in a large project called the South African-Norway Tertiary Education Development Programme (SANTED). SANTED was a Norwegian-funded, government-to-government development project which had as its major objective to enhance co-operation and build partnerships at the Universities of Namibia (UNAM), Eduardo Mondlane (UEM) in Mozambique and Witwatersrand (WITS) in South Africa, and to build capacity in both the theory and applications of biotechnology through the strengthening and introduction of relevant curricula. Biotechnology has become one of the University of the Witwatersrand's (WITS) important research areas, in accordance with the global trend within the discipline. Globally, universities, research institutions and industry are working towards the development and application of biotechnology. In recognition of this global trend, the University of Namibia (UNAM) has introduced new courses in Biotechnology to the curriculum.

Each of our individual ideas and views can influence the development of the biotechnology curriculum to ensure long term sustainability in an African setting. This research will involve questionnaires and informal interviews to find out your views on biotechnology. All data collected will be used to inform the biotechnology curricula at our Universities. The data will be analysed using the constant comparative method, which is a method of data analysis involving comparing concepts or categories coming from one data set with concepts coming from another data set, and then looking for relationships and themes between these concepts. This research will lead to a PhD and the data collected will be reported in my thesis. The raw data will be kept for the two to three years that the research is being carried out, after which it will be destroyed. Participation is voluntary and all participants will remain anonymous.

Yours sincerely

Jean

Semi-structured interviews with teachers/lecturers: Proposed interview questions

School of Molecular and Cell Biology, University of the Witwatersrand,

Private Bag 3, WITS 2050, South Africa

Mrs Jean Mollett

Telephone +27 11 717 6363

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These questions are broken up into sections to acquire personal background and worldview relating to biotechnology, Teaching and Learning information and student background.

Personal background

1. What is your home language?

2. What is the language of instruction of the university and in your classes?

3. Do you use code switching in your teaching?

4. Do your students use code switching in group work and/or in practical laboratories?

5. What is your qualification background?

6. For how many years have you taught biotechnology?

7. Who or what motivated you to learn biotechnology?

8. What is it about biotechnology that specifically led you to want to teach it?

Biotechnology worldview

9. What does the word biotechnology mean to you?

10. What are your views on genetically modified (GM) foods?

11. Are you happy to use GM foods in your family meals?

12. When you do grocery shopping do you consciously check to see if the products have GM status?

13. What do you think of the government's policies on GM?

14. Why do you think the government institutes laws on GM?

15. Do you know of any beliefs, maybe cultural or religious, that may have an affect on student learning of genetically modified organisms, foods or products?

16. Are there any biotechnology practices that make you uncomfortable?

If so, could you explain?

17. Do you have access to the latest biotechnological research and how it's being implemented? What do you think of this?

Teaching and Learning

18. (a)Please describe what teaching methods you use (e.g. do you use the chalk and talk method, PowerPoint presentations, debates or seminars?)

(b) Which do you think are most effective in terms of student learning?

19. How do you think practical laboratories contribute to the teaching of biotechnology?

20. How do you encourage high level thinking in your classes?

21 (a). What kinds of assessment practices do you use (e.g. formative vs. summative assessment/ practical tests/ questionnaires/ no summative assessment)?

(b). How do you think these assessments assist students in learning?

22. Do you find out what students already know or have experienced in this field as a teaching strategy? If so how do you use this knowledge in your teaching?

23. What areas do the students struggle with most to understand? Why do you think this is so?

24. What are the special considerations that you think need to be taken into account in teaching biotechnology?

25. What are the profiles of your students entering these courses i.e. are they students wanting to get into medicine eventually or have they come by some other route, and are now doing biotechnology quite by chance?

26. What are your student throughput rates and how many students change during the course of their undergraduate degree to pure biotechnology subjects?

Cross-border Teaching and Learning

27. In what way does the biotechnology programme design conform to your institution's mission statement?

28. Would you recommend having lecturers from other Universities contributing to your teaching? Is so, please give reasons for your answer.

Biotechnology courses

29. What factors have led to the development of your biotechnology programme?

30. What do you think the components are that students need to be trained in to develop as competent biotechnologists?

31 (a). What biotechnology subjects do you think are important for students to learn with regard to the economy in your country?

(b). How do you think these courses improve the employability of your students?

32. Do you have any other comments regarding the Teaching and Learning of Biotechnology?

33. Do you have any questions?

Thank you so much for taking time to participate in this research.

Proposed questionnaire questions for students

The learners will be a convenience sample from the final year undergraduate Bachelor of Science (BSc) students at WITS and UNAM. The questions are broken up into sections to acquire information on personal background, Teaching and Learning information and worldview relating to biotechnology.

Personal background

1. What gender are you? (Tick)

Male	Female

2. What is your home language?

3. What language are you taught in?

4. Do you use code switching in group work and practical laboratories? (Tick)

(**Code-switching** is the use of more than one language at the same time in conversation. People who speak more than one language sometimes use bits of languages when talking to each other.)

YES	NO

5. Does it help you to understand the information when you code switch with your peers? (Tick)

YES	NO

Teaching and Learning

6. What sort of lecture styles are you most comfortable with?

7. Do you think practical laboratories help you understand the concepts better? If so, how do they help?

8. How do you know when you really understand the information you have learnt in the class?

9. Which of the biotechnology courses you have done have you enjoyed the most and why?

10. Can you approach your lecturer if something is worrying you about the content or action of biotechnology?

11. What sorts of assessments help you understand the concepts and the content best? (For example, class tests, essays, practical application tests, tutorials or any other form of assessment you have been exposed to)

12. What do you find most difficult in biotechnology subjects (For example, volume of work, foreignness of ideas, …)

13. Would you recommend having lecturers from other Universities and countries contributing to your learning? If so, please give reasons for your answer.

Biotechnology worldview

14. What does the word biotechnology mean to you?

15. Describe your biotechnology learning experience. (This can be in the classroom or general experience outside of the classroom.)

16. Who or what motivated you to learn biotechnology and why? (This can be anyone or anything or an event in your life)

17. Describe a class room situation where you felt you were really learning to do biotechnology. Briefly mention the work you were involved with that made you think that this was the work of a biotechnologist.

18. Is what you are learning in biotechnology ‘believable’ to you?

19. How acceptable to you is what you are learning in terms of your community beliefs? Please explain.

20. Do you think biotechnology knowledge is valuable? If so, please explain why you think so.

21. Do you think biotechnology is potentially harmful? If so, please explain.

22. Is there anything in your biotechnology classes that you would hesitate to tell people in your community about?

23. What are your views on genetically modified (GM) foods?

24. Would you use GM foods in your families?

25. What do you think of the government’s view on GM?

26. Do any biotechnology practices make you uncomfortable?

If so, please explain.

27. Do you have access to the latest biotechnological research and how it is implemented? If so, how do feel about it?

28. Do you have any other comments you wish to make.

Thank you so much for taking time to participate in this research.

Appendix C

Sample of transcribed questionnaires with UNAM and WITS student responses to questions 14 and 23

The student responses have a number which is the number for that particular student transcript and the responses are in different colours to make it easier to follow one particular student's responses throughout all the questions i.e. they are colour coded.

UNAM (2011)

14. What does the word biotechnology mean to you?

1. The application of biological system to technology

2. Application of biological technology to produce products

3. The use of technology advanced or modified organism for production of useful products.

4. Its just a combination of biology and new technology to our advantage for instance using microorganisms to produce product of interest or any application of technology that uses biological systems to produce goods.

5. The use of technology in biology

6. Technological ways of improving biological environments and "entities"

7. ------------------

8. Manipulating things to give better quality ones using biological systems

9. Technological biology: basically using biology in technological area. In food, medicine, agricultural or marine areas.

10. Biology combinant (sic) with technology

11. The use of microorganisms to produce useful products in fields such as agriculture, medicine, industry, pharmaceuticals

12. Is the application of biological process to industrys (sic) in order to produce products.

13. Use of organisms (like microorganisms) in the world of technology

14. Different means of technology that are applied in biology to help solve problems (such as diseases and poverty) in the health sector. This is the part of biotech that is most NB to me. It is also used in food products, agriculture, dairy etc.

15. Biotechnology is the use of living organisms to make a profit. It includes a lot of fields such as biochemistry, embryology, proteomics genomics etc.

16. __

17. ---

18. Technological in science and biology.

19. Is the application of technology to biological process in order to make profit (sic).

20. The technology used in plants, humans.

21. Use of technology to understand biology

22. The use of biology and new technologies to make life easier.

23. Helping to improve the population and well being

24. ----

25. The use of microorganisms for human use.

26. Biotechnology helps me to understand the future and how we can fight drought, femine (sic) and malnutrition (sic) as well as diseases prevailing in Africa as well as help in developing our country.

27. The technology around biology. E.g. GMO's etc.

28. Biotechnology is a door to a new world which I believe will be a better one, with the introduction of new drugs e.t.c.

29. The manipulation of biological organisms in industry and agriculture to make products.

30. The use of biological system and derivatives thereof in technological applications.

31. Is the study of manipulating or changing things for better or faster production.

32. The application of technology to biological processes.

33. The use technology in biology

34. The application of biology to make profit.

35. Manipulation of biological processes and organisms for human/environmental /animal benefit.

36. Producing specific products using biological techniques.

37. The modification or use of biological organisms for human benefits.

38. It means all technological processes that use biologicall (sic) systems like plants, animals and microorganisms by altering them to utilize them in something that can be commercially beneficial.

39. Refers to the collection of technologies that utilize organisms or their products to make usefull (sic) products, thus improving medicine, agriculture and industries.

40. The use of biological organism s with combined todays (sic) technology to produce useful products.

23. What are your views on genetically modified (GM) foods?

1. ---

2. Harmful organisms interfering with normal development of an organism taking them

3. They are just food, and of better nutritional value.

4. That all countries should allow their use but not to replace our original food without any modification because we still don't know their long term effects.

5. Can reduce the poverty rate in Africa

6. Scarey, wouldn't wana eat them. Just the thought of someone tampering with food we already have to make it, i don't know technical (sic).

7. ---------

8. They can be produce within a shorter period of time and in great quantity to meet the demand

9. As long as it doesn't kill you i guess its ok. Usually what they do to the food is increase nutrient levels which your body needs, so if nature fails, science steps in and comes to the rescue.

10. It is a fast way of producing food to feed starving nations

11. I believe that GM foods would be a great advantage to the growing population and the changing environmental and health conditions.

12. I would say they have both advantages and disadvantages, hence we cannot really do away with them because they can even be used to alleviate poverty, help with drought reliefs

13. GM foods have improved nutrient contents; they should be localized in countries

14. If GM food companies were not so keen on making so much money out of suffering people then i would be totally ok with the production of GM foods.

15. I think genetically modified foods are need in developing countries, but they should be carefully consumed because future consequences of GMO foods are not known.

16. ---

17. Good thing even though its (sic) not carried out and allowed in Namibia

18. I do not highly recommend it and would like to stay away from them as long as possible

19. Its a good way to provide food to less fortunate people, and cheap especially for countrys that are facing drought and war (sic).

20. Could have solved the problem in Somalia

21. They should be allowed because in countries like Somalia, they may help in reducing poverty by providing foods, jobs etc. for those people.

22. Unethical it is not natural, but then again it could improve our lifestyle, make us healthier and strong 2 (sic).

23. They have a lot of advantages but they are also harmful in certain cases.

24. They are good

25. They can help us fight mulnutrition (sic) and hunger at large scales.

26. I don't seem to have a negative view on it. Sometimes it can be helpful in feeding the nation. The industry should just be truthful to the nation so they can have choice.

27. So far, no harm has been done so they are the way forward I think.

28. Although they are impacting in drought stricken areas, we don't know what damage or disasters will they cause in the future.

29. Has both a good side = feeding the human population that is staving (sic). Bad side = may have medical side effects.

30. I do not mind eating GM foods, since a lot of the food is already genetically modified with out us knowing.

31. On one side I'm for them because they represent hope – according to what I've read about them. On the other hand however, they could be a threat to the welfare of organisms (living) since the long-term effects are unknown.

32. I think they are helpful in terms of droughts and can actually prevent starvation.

33. Unknown health risks. Provide more nutrients.

34. GM foods should be produced but in a properly controlled way to avoid the hazards and concerns that come with their production. Useful, e.g. hunger striken Somalia. Etc.

35. They are good examples of the benefits of biotechnologyt and can be of great help in cases of drought.

36. GM foods should be used in society but at certain levels. One should not have a whole plate full of GM foods for dinner.

37. I am not against the use of GM food that is why I explain to people about their use and appreciating their role in the universe.

38. I think its great idea. These way, we can have food stability. However, since we don't know the future effects of GM foods, we should be cautious because no one knows the long term effects in the long run.

39. They must be clearly labelled "GM foods"!

40. They are quite helpful, but alternative care must always be taken into consideration, especially in controlling gene. How be GMOs and natural environment.

WITS (2011)

14. What does the word biotechnology mean to you?

1. It means the application of biological organisms in technological procedures.

2. Use of microorganisms to understand nature and develop new ways and simpler ways of doing things.

3. It means the application of biological organisms/biologically-produced chemicals to solve issues (like biomimcry (sic) encouraging different engineering designs).

4. Using current technology to aid in the understanding of life systems.

5. The application of technology and technological processes to better biological processes e.g. the use of tissue culture to mass propaget (sic) plant species.

6. Use of technology in a biological, eco-friendly way.

7. The use of biotechnological techniques in the manipulation of biological systems/organisms for the benefit of humans.

8. The application of biology in industries

9. Technological advances in the field of biology.

10. Applying microbiological concepts and microorganisms in the industry.

11. Incorporating technology with microorganisms to improve scientific methods such as wine making...

12. Using biological techniques to assist in making life and processes easier.

13. Application of biology to better our lifes (sic).

14. Using biological organisms to creat (sic)

15. Using technology to study biological courses.

16. The use of biology in the form of molecular and cell biology to drive technology and development of solutions to problems in industry and agriculture.

17. Biological applications/practices

18. The application of biology together with technological approaches in order to improve the quality of life e.g. agriculture.

19. Using current technology to make biological research easier and more accurate.

20. The combination of biological processes or concepts in biology and using technology to better them.

21. Improvement in any field of science where biology is the central focus point.

22. Genetically engineering or modifying of organisms or plants so that they can meet our demands.

23. Biotechnology to me means the application of microorganisms to make life easier or improve the standards of living

24. It means that there is a whole field that creates jobs for people with a science degree. It creates many opportunities to solve problems such as starvation, disease etc.

25. Applying biological agents and methods to develop technology.

26. It means new discoveries.

27. How living organisms can be altered to benefit humans/ the environment.

28. Biotechnology involves the use of living organisms and processes in engineering e.g. genetic engineering

29. The use of new/old technology in a biological field to make ones (sic) life easier.

30. ---

31. Manufacturing of new products by manipulation of certain genes

32. Technological research in the biological field; advances in technology with regards to biology.

33. Technological research in the biological field.

34. Application of biology and biological; systems to the technology to improve lives.

35. It is the use of the metabolic activities or by products to obtain much needed resources.

36. The manipulation or modification of genes in order to produce goods and services.

37. The use of microorganisms in industry as a means of food production, environmental conservation etc. this takes place through the applications of Microbiology, Genetics and cell biology.-

23. What are your views on genetically modified (GM) foods?

1. ---

2. It's a good thing because the population is growing more and more.

3. Good idea in developing countries to increase productivity per plant. However, the monopoly of companies creating GM sterile seed seems more ethically iffy.

4. The use of genetically modified foods should not provide adverse health complications in the long run.

5. I think they are generally safe and are one of the positive results of the contribution that biotechnology has made to our production process.

6. I think it is good to have them to help the world food shortage.

7. They help in lessoning the food prices as a whole, although still sceptical about them

8. I have no problem with them

9. I think they are a good solution to food shortages that may be experience.

10. I don't have huge a huge problem unless it could have huge impacts on health.

11. If they won't put our health at risk, then I'm all for them.

12. I know that its better than using chemical pesticides to use genetically modified crops as pest control. However, i'm (sic) sceptical about its effects long term on the human race. Food is essential make up of our bodies and effects mental balance. A build up of these foods perhaps affect genetic structure (genome) and change metabolic behaviour of individual.

13. If they give the nutrition required without any harmful effects then, I do not mind them. Mass production therefore can feed a lot of people. Withstand harsh environment.

14. I think they are great as long as they don't cause harm in humans, if we don't genetically modify plants to be resistant to path0ogens then they might get wiped out and there won't be any money to feed the ever increasing population.

15. They are ok but they can have side effects in the long term.

16. If proper screening is carried out and proper testing procedures and trials are conducted I believe that GM foods are completely safe.

17. Some are more good for you than others. If they are being modified to be more beneficial then I'm all for it.

18. They are beneficial to the community.

19. I have no problem with it and feel that it only benefits the community.

20. I think they are fine

21. Genetically modified foods have helped billions of people worldwide (see Norman Borlaug). I love GM foods.

22. I'm against them, I like organic foods.

23. I don't have a problem with GM foods because I believe they are the same as natural foods except that GM foods are modified a bit e.g. enhanced nutrition qualities.

24. If tests on animals etc. have been successful, GM foods can save money, time, prevent disease and starvation. It can benefit many people provided that its safe and affordable

25. GM foods may be cheaper, but in the long run will have bad influences on human health as it will interfere with the development of humans.

26. I do not mind that they are there as long as they do not harm anyone. Its (sic) OK.

27. I think they are good. I ate lots of GM foods in America because they were cheaper but were still nutritious. They are a potential answer to world hunger.

28. GM foods are not good. Anything can go wrong during modification.

29. If it uses “practical” stuff then its (sic) good however if it uses anything harmful. In the long run/short run it isn’t.

30. It’s good because not all foods are accessable (sic) and since our population is increasing drastically having GM foods is actually a great idea!

31. GM foods solve hunger problems that we are faced with today.

32. They are beneficial in terms of food loss minimization; Africa, in particular, is exposed extensive food loss in the form of crops due to the reduced resistance of plants to harmful pests/parasites.

33. I don’t eat them. Gross.

34. GM foods are still good because they are also nutritious but free of diseases.

35. I’m ok with it because of how fast is the world’s food supply loss. It could even be due to pests.

36. That worries me because we may not be aware what effects they may have in our general health.

37. Im (sic) very pro-GM foods. It is, unfortunately, one of the only ways to prevent food shortages.

Appendix D

Publication 1: Biotechnology capacity development in southern Africa: Aspirations, Inspirations, and Perspirations

Mollett J. and Rey C. **2008** Biotechnology capacity development in southern Africa: Aspirations, Inspirations, and Perspirations. XIII. IOSTE Symposium, The use of Science and Technology Education for Peace and Sustainable Development. 21-26 September 2008, Kuşadasi, Turkey. ISBN 978-605-5829-16-2

Abstract

This paper describes the process and approach of biotechnology capacity development in three universities in the Southern African Development Community (SADC) region. The objectives are to enhance co-operation and build partnerships at the Universities of Namibia (UNAM), Eduardo Mondlane (UEM) in Mozambique and Witwatersrand (WITS) in South Africa. The principal reason for introducing or strengthening the undergraduate curricula in biotechnology at the institutes is to build capacity in both the theory and applications in this field, especially in the critical areas of crop agriculture, animal and human health and bioprocessing. The approach of WITS, where biotechnology is already established, is to engage with UEM and UNAM in a participatory collaborative process, rather than being prescriptive. This falls within the objectives of the SADC protocol on education, one of which is to maximize the effective utilization of existing expertise, institutions and other resources for education and training and to ensure long term sustainability. To this end it will also eliminate needless and costly duplication at the tertiary education level and facilitate staff and student exchange between institutions. Through the participatory process, we have adopted a qualitative approach to research which engages with the teacher and learner epistemologies of science and biotechnology at these diverse, multicultural Southern African institutions.

Key words: biotechnology, epistemology, teaching and learning

Publication 2: Sociocultural and human values in biotechnology tertiary education in southern Africa

Mollett J., Rey C. and Cameron A. **2010** Sociocultural and Human Values in Biotechnology Tertiary Education in southern Africa. XIV IOSTE 2010 Symposium, Socio-cultural and Human values in Science and Technology Education. Proceedings. 13-18 June 2010, Bled, Slovenia. Editors: Borut Lazar & Robert Reinhardt. ISBN 978-961-92882-1-4

Abstract

It has been established that epistemological barriers play a significant role in effective teaching and learning. The aim of this research is to investigate the impact of African epistemologies,

including sociocultural and human values, on learning in the field of biotechnology. The study intends to investigate what epistemological barriers there may be for the teachers and learners in the field of biotechnology at the Universities of the Witwatersrand in South Africa and the University of Namibia in Namibia, with the focus on facilitating capacity development through teaching at the tertiary education level. This study will hopefully provide a platform for the development of a biotechnology curriculum responsive to African needs and epistemologies. The value of this study lies in formulating and developing the biotechnology curriculum, and Teaching and Learning (T&L) of it, an 'African product', rather than as an export of decontextualised western science.

Keywords: Biotechnology; cross-border tertiary education; African epistemology

Publication 3: Crossing Borders in Biotechnology Tertiary Education in southern Africa

Mollett J.M., Cameron A. & Rey M.E.C. **2011** Crossing Borders in Biotechnology tertiary education in southern Africa. The International Journal of Learning 18(5): 37-48. ISSN: 1447-9494 © 2011

Abstract

The research problem identified through a participatory and collaborative process of biotechnology curriculum development in two SADC institutions was based on the understanding that science curricula need to take cognizance of 'worldview' and the impact this may have in the context of teaching and learning. Worldview refers to the understanding that each of us has presuppositions about what the world is like. In the context of southern Africa, the term "epistemological access" has been coined to describe the barriers to success that are linked to worldview. Studies conducted in South Africa and other parts of the world have identified that worldview differences can lead to barriers to learning in science, which itself presents a particular way of understanding the world. In the light of these studies the purpose of this research study is to investigate the potential barriers to learning in two southern African universities in the context of the biotechnology curriculum. The research study has focused on how African epistemologies should be taken into consideration to facilitate capacity development in biotechnology at the tertiary level. The research aim is to facilitate the development of a culturally sensitive, generic biotechnology curriculum which reaches across both literal and cultural borders and is relevant to these countries. The new curriculum would then represent an 'African curriculum', which recognizes the inherent cross-cultural experience between the learners' life-world and biotechnology.

Key words

Epistemological access, Cross-border Teaching and Learning, Cultural border crossing, Biotechnology, Worldview, Multicultural universities

Appendix E

Ethical clearance certificate

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Division of the Deputy Registrar (Research)

HUMAN RESEARCH ETHICS COMMITTEE (NON MEDICAL)
R14/49 Mollett

CLEARANCE CERTIFICATE	PROTOCOL NUMBER H100 202
PROJECT	Tertiary education capacity development in biotechnology in the Southern African development community
INVESTIGATORS	Mrs JM Mollett
DEPARTMENT	Molecular and Cell Biology
DATE CONSIDERED	12.02.2009
DECISION OF THE COMMITTEE*	Approved Unconditionally
NOTE:	

Unless otherwise specified this ethical clearance is valid for 2 years and may be renewed upon application

DATE 11.03.2010

CHAIRPERSON ....
(Professor R Thornton)

cc: Supervisor : Dr A Cameron

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10005, 10th Floor, Senate House, University.

I/~~We~~ fully understand the conditions under which I am/~~we are~~ authorized to carry out the abovementioned research and I/~~we~~ guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/~~we~~ undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**

Mollett
Signature

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix F

Table 2: Summary of analysis of Lecturer Interviews (WITS)

Conceptions	**KNOWLEDGE**	**SKILLS**	**APPLICATIONS**	**AMBIVALENCE**	**RISK/HARM**	**ETHICS**	**Notes**
Biotechnology Background							
Career opportunities	X		X				
Benefits mankind	X		X				
Useful	X		X				
S.A.advanced in biofuel production	X	X	X				
Use of organisms Useful in Industry/environmental management Biology +technology to solve problems	X	X	X				
Biocontrol agents and mycopesticides tested	X		X	X	X	X	
English for information Language of science	X						
Potential limitless	X	X	X				
Make money Commercial outcomes			X				

Misconceptions –controversies				X			
Misinformation about GMOs				X	X		
Biosafety (GMO Act)	X			X			
Economic importance	X	X	X				
Funding Internal/External				X		X	
No fear when understand the technology	X						
Research on animals and insects not acceptable - religious and cultural beliefs interfere with learning -uncomfortable with research on animals e.g. glow in the dark pig – no purpose or benefit -GM products must be assessed on a case-by-case basis for benefits and risks	X			X		X	
Government Laws protect scientists and environment -political side - win votes -rational and progressive DST transformation (-innovative and rich -benefits and problems) SA Government have legislations for labeling Labeling of products important for consumer – freedom of choice -Misconceptions about Gm foods because of bad publicity -Educate communities on GM -SA laws are very thorough Scientific advisory board that advises the government and reports on all GM produce. The committee does the risk assessment and informs the Government on the science and biosafety issues. Legislations are important because of uncertainty and concern for biotechnology practices	X			X	X	X	

GM foods benefit communities (-avoid capitalistic gain) Prefer to eat GM food over food exposed to pesticide	X		X	X		X	
Lack of understanding of the technology (public and students) -Local communities needs to be educated on GM so they can make choices	X		X				
Traditional biotech good starting point	X	X	X				
Stem cell research - religious issues -medicine value -not such an uncomfortable issue as can be taken from umbilical cord and grown in the lab.	X	X	X	X	X	X	
Safety issues (benefits at expense of evaluating safety issues)	X			X	X	X	
GMOs for development of sustainable agriculture	X	X	X				
New Age Beliefs (-consumer attitudes)	X			X	X	X	
Internet = access to biotech	X	X	X				
Heal(medicine), Fuel (industrial), Feed (Agricultural)	X	X	X				
Teaching and Learning Biotechnology							
Student beliefs do not affect learning about biotechnology but do affect whether they consume or buy a product Religious ideas may not allow openness to the technology i.e. not open for discussion or listening) -Science students should separate beliefs from philosophical social issues	X			X		X	Collateral learning
Practical laboratories reinforce theory	X	X	X				Scientism

-Empirical verification -Hands-on experience -Interact with the work -Help with learning and appreciation							
Build on traditional Biotechnology techniques -To avoid misconceptions	X	X	X			X	Solutions
Borders not defined in Biotech (-Bioremediation to medical diagnostics skills the same)	X	X	X				
African examples -African solutions from indigenous biota and resources	X	X	X				Solutions Biomimicry
Guest lecturers -from African countries -Globalization positive impact -use techniques from West (facilitated by conferences , media, internet) -different perspectives and domains of expertise -energizes the students	X	X	X				Solutions
Identify ourselves as African University	X	X	X			X	Solutions Moral obligation
Train rural communities	X	X	X			X	Solutions Moral obligation
Thrusts: Industrial and Disease oriented research	X	X	X				Solutions
Students struggle with mathematics problems and analyses – relating the different parts together.	X	X					Analysis
Peer presentations good learning tools –grilled by peers and leads to argument -results in good preparation	X		X				T&L Solutions

Designing experiments for medical, industrial or commercial use	X	X	X				T&L Solutions
Continuous and varied assessment -encourage reading the newspaper and watching news- up-to-date with current issues which leads to understanding why learning and what the applications thereof are. -practical reports on specific questions leads to critical distillation and students think cohesively about the overall concept	X	X					T&L Solutions
Biotechnology Courses							
Scientific skills and knowledge of organisms	X	X					
Agriculture and environmental problems solve (-Economy)	X	X					
Background knowledge (-paper comes from wood-Paper and Pulp Industry) Need good foundations to get to specific levels - fundamental before get to applied side of the concept	X						
Homegrown research (-Biotech old knowledge and IK)	X	X					
Employability -Strong industry outcomes link –products to the market -commercial interest leads to fundamental research projects -courses that are too diverse dilute student knowledge and skills and they not trained to be employable.	X	X	X				
Lack trained people but train a lot (-need more academics to attract more collaboration)				X			

Share ideas and collaborate	X		X				
Students want to champion the cause	X	X	X				Power Empowerment
Benefit community	X	X	X				
Business aspect –proof of concept to product and commercialization -Start sustainable businesses in communities			X				Sustainable Economy

Table 3: Summary of analysis of Lecturer Interviews (UNAM)

Conceptions	**KNOWLEDGE**	**SKILLS**	**APPLICATIONS**	**AMBIVALENCE**	**RISK/HARM**	**ETHICS**	**Notes**
Biotechnology Background							
Biotech heart of conducting medical research and for agriculture for food security	X	X	X				
Improve livelihood of small scale farmer	X	X	X			X	Moral obligation
Solve real life problems			X			X	Moral obligation Solutions
Scientific validation (nutritional value and medical properties of plant products)	X	X	X			X	Moral obligation
Micropropagation and cloning	X	X	X				
Drug development	X	X	X			X	Moral obligation
Make a profit			X				
Ethnomedicines -validate traditional healer knowledge of plants	X	X	X			X	Solutions

Genetic modification -genes taken up by different genomes -proper channels of research, test and risk assessment	X	X	X		X	X	
Genetically modified foods	X	X	X		X		
Well informed schools and public to be able to choose	X					X	
GM food labeled to be able to choose	X					X	
Use biotechnology to our advantage (-careful to preserve gene diversity of landraces) -commercial vs. subsistence - monoculture vs. intercropping Crops of future = indigenous crops, subsistence farmers backbone of food security) Issues of commercialization, accessibility and sustainability Biotechnology vs. Genetic diversity	X	X	X	X	X		
Do not want to eat GM foods without knowing -When know may be buying GM labeled then compare labels for organic -African consumers buy according to price -Not worried Namibia does not allow GM products -Only check for expiry date	X			X			
Gov laws and policy best for now economically, because of beef industry - export to EU. -Restrictive -biased -unscientific -uneducated - allows flexibility	X			X			
Biotechnology does not challenge beliefs -Cultural religious beliefs do not affect learning	X			X		X	

biotech it is their perceptions							
Playing God Interfering with God’s Power Science belittling God -Can’t appreciate the scientific processes especially of evolution and adaptive biology						X	
Safety concerns regarding tinkering with animals					X	X	
Understanding biotechnology techniques leads to acceptance	X						
New generation open to new technology	X						
Biotech debate emotional aspect not based on informed fact. -uninformed public debate scares people					X		
Viral engineering could be dangerous	X				X		
Pay too little attention to biodiversity -Theft of our samples with rich genetic variation	X				X	X	
GM for the good of mankind or the demise of mankind makes uncomfortable, but still continues research	X			X	X		
Recombination between different genomes/ switching genes between organisms	X		X		X		
Funding to access International workshop and conferences	X	X	X				
Teaching and Learning Biotechnology							
Practical laboratories very important -Practicals improvised and simple -Lack of equipment and infrastructure	X	X	X				
In-service training Hands-on practice	X	X					

Field trips	X	X	X				
No model organisms in Namibia. Law not implemented	X						
Different cultural ethnic schooling backgrounds		X		X		X	
Biotechnology students are Wanna-be-medics and pharmacicts				X			Affects the transfer of knowledge
Very low class attendance							Affects the transfer of knowledge
Biotechnology Courses							
Capacity building by associations with community	X	X	X				
Agricultural and mining based -biomining	X	X	X				
Cross border: Collaborative and sharing -inclusivity of knowledge -quality control	X	X	X				
Good background basic knowledge -Inspiration -Innovation -genetics, biochemistry and microbiology	X	X	X				
Poverty alleviation	X	X	X				
Disease eradication	X	X	X				
Competencies such as fingerprinting for conservation genetics	X	X	X				

Table 4: Summary of analysis of Learner Questionnaires (UNAM)

Conceptions	**KNOWLEDGE**	**SKILLS**	**APPLICATIONS**	**AMBIVALENCE**	**RISK/HARM**	**ETHICS**	**Notes**
Biotechnology Background & Meaning							
Better society - Cure disease (to help people) -improve crop production -cure cancer -fight TB -Nutritious food for patients	X	X	X			X	
Safer world Solves problems Helps appreciate nature – Biomimicry	X	X	X			X	Biomimicry
Become famous /remembered for something	X	X	X				
Use of microorganisms to produce food products, medicine	X		X				
Manipulate bacteria, fungi, plants animals for better quality	X	X	X		X	X	
Beneficial to humans and environment	X		X			X	

(bread baking, bananas without seed, Big red oranges)							
Gene manipulation	X	X	X		X	X	
Improves current biological systems (-yeast in making bread -plants with better characteristics -grow plants quickly -agriculture and industry applications, leading to higher yields in less space Crops and animals to develop our livelihood and for economic use)	X	X	X				
Helps understand the world of genetics	X						
Highly sophisticated equipment -gel electrophoresis -bioreactors	X	X	X				
New experience	X						
GMO and environment debate	X						
"Change Africa from poverty"	X	X	X			X	Moral obligation
Microbiology stepping stone to biotechnology -bacteria with vectors esp. Ti plasmid -bacteriophage -parent (into soil, agriculture and chemistry) -lecturer	X		X				
Effect quality and quantity of product			X				
Bacteria modify plant genomes	X	X	X		X	X	
DNA extractions and insertions: from and into bacterial, plant and animal cells	X	X	X		X	X	

Biotechnology is a science not just dreams because can see results e.g. transgenic plants	X	X	X				
Whole new world -foreign ideas -difficult to imagine microorganisms and molecules -Concepts new and different, need to adapt to them -new words e.g. primer	X						collateral learn and border cross
Application of concepts difficult/challenging		X					
Practical applications for career - medical diagnoses -Drug production -plant development - lack of local applications			X	X			
So amazing – can't really believe Or can hardly believe	X						
It is an inspiration -makes life easier	X						Perception
Includes many fields: biochemistry, embryology, proteomics genomics…	X						
Helps understand the future -how to fight drought, famine malnutrition, and disease -how to develop a country	X	X	X				
How to make a profit -to make systems commercially beneficial -improve products involved in medicine, agriculture and industries	X	X	X				

Biotechnology practiced from young age, only realized it is called biotechnology at University -brewing traditional drink Oshikundu	X	X	X				
Impacts our lives -development and social impact -bioleaching in mines; crime scene investigation -allows to make choices -can make comparison between what is learnt and outside environment	X	X	X				
Enabled understanding and helped to answer questions in community – application in everyday life -can save lives	X	X	X				Empowering Rational
Needs to be run by people with hearts not just for money						X	Emotion
Bioterrorism					X		Power
Believable if Understandable (understanding leads to acceptance) -Makes sense -complex concepts need visible proof -practical evidence -with science anything is possible	X						
Not acceptable in community because there is lack of information / highly acceptable because of traditional biotechnology practices i.e. brewing of traditional food, drink and baking	X			X			
Acceptable because it interests me and God created it.						X	
Against communities ethics , (use of GMOs,	X	X	X	X	X	X	Scientism

manipulation of DNA) -Community beliefs different from scientific beliefs (not many people believe in the gene or DNA) -science and religion do not mix -alterations caused by mankind to species is regarded as unethical Acceptable can develop our communities and lives e.g. by going to hospital for needed treatment. Stereotyped ideas and not understanding - therefore do not believe biotech can change lives Biotech is similar to community practices just polished applications Some community beliefs are not beneficial – they are nonsense Helps explain usefulness and significance to chief Believe in power of human mind therefore acceptable Don't believe in non-scientific beliefs that can't be proven.							
Biotechnology is hope							Hope
Lethal viruses could result Unknown allergens in new products Unknown long term effects- negative effects on environment Gene escape –superweeds -Do not use animal genes in plants -Manipulation of Hox genes in model organisms to understand pathways					X		
Properly controlled research -to avoid concerns that come with their	X				X	X	

production							
Will not share with community: -Beer brewing -GM food -Sexual reproduction i.e. genes passed on by mating (#4green p34) -Suicidal genes in plant breeding -Superweeds -HIV tests				X		X	
Proper explanation can solve fear of biotechnology and clear up misunderstanding -will not believe can clone goats in their kraals	X					X	Moral obligation
GM foods - better nutritional value -must not replace original food -can reduce poverty in Africa -will not eat GM food -produced quickly and high quantities -science stepping in if nature fails -Advantage to growing population changing environment and health conditions -Improved nutrition therefore localized in countries where needed -Needed in developing countries but should be carefully consumed -Need truth so consumers have a choice -Must be clearly labeled -Should not eat a whole plate of GM foods -Save Money, feed more, save time -Nutritious prevent health risks	X		X	X	X	X	

-Prefer naturally occurring food							
Cannot motivate family to eat GM foods because do not know the risks Or will motivate if no side effects , labeled to avoid allergies and because DNA is broken down in digestion process	X			X		X	
Government view: Some think allow some think don't -GM not released to the public -Not trustable -Make decisions on assumptions and speculations -Do not understand biotech -Guess we import food from other countries that contain GMOs -Threat – larger ethical debate -Expensive – another way for biotechnological companies to get money -economic and political reasons – export free-range natural beef to EU do not want to be associated with GMOs..				X	X	X	
Uncomfortable -human cloning -Animals as test subjects -cloning -killing animals				X	X	X	
Most UNAM students feel do not have access to latest biotechnological research.	X						Not confident in T&L Structure/institutio n
Teaching and Learning Biotechnology							
Cross-border teaching gives:	X	X					Solutions

-explore the world while still in our country -assurance that learning the same as other universities (quality control for the learner) -share knowledge with outside world and broaden ours -others better equipped with knowledge from different areas – keep us updated -learn other cultures, traditions and values -Same lecturer for all biotech subjects; therefore diversity would be good -New ideas and skills -different strengths and approaches							
Understanding through hands-on practical laboratories, tutorials, essays and interactive discussions; field trips; tests. Teaching needs PowerPoint presentations with notes available; different teaching styles help with understanding.	X	X	X				
Practical laboratories give experience, make theory understandable because can visualize – seeing helps understanding of unfamiliar concepts -allow applications of the theory -prepare for life challenging tasks	X	X	X				
Practical laboratories verify textbooks	X						Textbks not the only truth
Own research vital for understanding	X						Empiricism/ scientism
Prior knowledge bread making, beer brewing and bioremediation	X						
Understand when can apply the theory in community or on oneself -explain to peer, friend, partner, parent in	X		X				

vernacular -interpret in own words -can actually ask questions concerning the work							
Biotechnology Courses							
Topics most enjoyed: molecular and Cell Biology; Plant and animal biotechnology; Plant genetic engineering; Recombinant DNA technology;	X						
Learn to appreciate nature -stay natural -do not play with nature	X					X	
Biotechnology course need large practical laboratory component	X	X	X				Moral ob-ligation Solutions
Implement the biotechnology courses in other African countries -development and sharing of problems facing our continent together	X	X	X			X	Solutions

Table 5: Summary of analysis of Learner Questionnaires (WITS)

Conceptions	**KNOWLEDGE**	**SKILLS**	**APPLICATIONS**	**AMBIVALENCE**	**RISK/HARM**	**ETHICS**	**Notes**
Biotechnology Background							
Improves commercial and industrial processes and products by economic improvement and product quality	X	X	X				
Production at industrial level with less chemicals- safer for environment and less pollution	X	X	X		X	X	
Solutions to man-made problems using biological organisms	X	X	X		X	X	
Microorganisms to produce biodiesel, beer, paper, bioplastics – reduces harmful elements being used and as by-products; -organisms altered to benefit humans and the environment -manipulating genes	X		X		X	X	
Biological products organisms for technological processes -More environmentally friendly -sustainable	X	X	X			X	

-economic process -for the agricultural and medical industry -microbes replace chemicals -moving forward in technology without strain on environment- environmentally friendly MCB to drive technology and development of solutions to problems in industry and agriculture							
Creates jobs -provide resources; produce goods and services ; food production and environmental conservation	X	X	X			X	
Able to see concepts and topics in everyday life	X		X				
Bettering our lives -new discoveries	X	X	X				
Helps make better decisions regarding everyday things and understanding of processes that may take for granted -Provides new and abstract views and ideas which helps to decide the consequences if actions are taken	X						
Creative, experimental and practical – everything learned in classroom applied outside; new and foreign ideas and concepts concerning processes in everyday developments -Bacterium inserting genes into plants ; cloning genes ; hormones in plants used to stimulate growth of many plantlets in vitro; microorganisms purify waste in sewage – replace harsh chemicals which damage the environment (bioremediation of sewage and industrial waste); turning pollutants into something useful; biosynthesis of plastics; Proteins of interest secreted by bacteria; Products such as insulin	X	X	X				Biomimicry

Foreign topics -complicated biochemical processes especially for bioreactors	X	X	X				
Biotechnology is different ways of generating products; -broad and opens up many opportunities Bioremediation; plant genetics biodiesel; -help people and the environment; -acid mine drainage; cleaning water using different types of bacteria; making beer; -Improve scientific methods -mass production	X	X	X			X	
Biological organisms in technological procedures			X				
Understanding nature and life systems	X						
Want to develop the world to be beneficial without causing any damage -high levels of cholera in home village motivated to study biotech as it is good for the community to have someone who knows how to purify the water.	X	X	X			X	
Many employment opportunities			X				
Hard to believe concepts first time hear about them – becomes clear and believable with understanding -evidence when see it is actually being performed in practical laboratories and evidence in everyday life. -Sometimes commercial applicability is questionable when processes are highly complex and unrefined Believable because it is practical and done by scientists; used in everyday life; It can be confusing –if dubious check the	X		X			X	Scientism

literature, esp peer-reviewed literature; other scientific papers with similar results and if able to do as well; Needs time to test, as benefits and harms economically and biologically, Aspects of evolution are not believable							
Acceptable in terms of community beliefs: Technology to improve industrial processes while exploiting the planet less; -Because atheist - because make own decisions and not going against the community -alternative solutions to community problems e.g. clean water issue; -get a better way of life Knowledge, progression and balance; make things more efficient and safer for environment; Morally better to reduce something like famine than to do nothing about it; Science is key to modern world; Knowledge concerning biotech is limited in the community, ideas would be welcomed with exposure and background knowledge; -must not clash with community beliefs; -ideas would be welcomed with background knowledge and if helping the environment; interest in science and the changes it can make; -community can benefit from it – preservation of food; broad minded and well-educated family; like science and nature; brings forth debate; Beliefs not affected because science is the solution to the problems in the world; -technically cannot play God, because cannot produce anything that does not already have a	X	X	X	X		X	Moral obligation

gene Acceptable, but in my religion beer and wine are not allowed; acceptable because religion is the study of the creator and science is the study of creation. -if it can be explained it can be accepted							
Unacceptable plants etc grow on their own – do not need help (however not grown commercially) Afraid of outcome, community against change and scientists seen as playing “God” Some believe GE is causing sickness and quality of GM food is not good; -people are scared of using microorganisms as beneficial, normally they are bad; Unacceptable in a community because the youth should live the ways their ancestors did; -human evolution -Science clashes with the natural ways of living -scientists playing God	X			X	X	X	
Valuable – new ways of solving old problems; efficient products with reduced chemical effluent produced and energy burned; Biofuels solving problems of using fossil fuels ; -electricity production using bacteria; save future of planet; Find a cure for cancer; GM foods b- benefits for poor countries; Save lives; -efficiency to current production methods and allows for more knowledge to acquired; -safer alternatives to chemicals – mitigate global warming; -medicines; -food security;	X	X	X			X	

-Solutions to pollution; -More food and improve the economy; -gathering knowledge; -solve agricultural problems e.g. insects eating plants							
Helps understand how the world around us works-how important microbes are to our existence	X		X				
Think in problem solving manner -improvement of life -beneficial to society(improves on scientific and traditional methods -sustain growth of industries such as farming (not lose money) -fixing man-made problems (e.g. oil spills cleaned up using bacteria)	X		X	X			
Potentially harmful -If in wrong hands -Not used correctly -Not fully understood -scientists careless -no risk assessment done -microbes mutate to harmful form -unethical experiments performed -if exotic organisms made that have no natural predators(may outcompete indigenous species) -may affect environment negatively -transgene outcrossing -change existing genes –insertion of genes into different organisms(don’t know what genes knocking out or whether mutating to make harmful) Proper regulation is necessary; if over-	X				X		

emphasized could foster complacency; Biological warfare; the chemicals used to study products in the lab can be toxic; -disrupt the environment; -may alter living conditions negatively; Introduction of new species may lead to loss of indigenous species and loss of biodiversity; fungal and bacterial organisms introduced into environment may pose risk to other organisms; If the information is not correctly understood; all cases should be examined separately; people involved qualified and understand the consequences							
Hesitate to tell community: Animal testing; stem cell research; (sensitive topics) -GM foods (people don't understand their benefit)and are scared to hear about them) -How dairy products are made e.g. yoghurt uses bacteria -Insect pathology (testing on insects is cruel) -cloning plant -that fungi and bacteria are used in making food -Use of microorganisms ("germs") in transforming foods; The fact that you can make plants produce what you want them to; -Wouldn't share ideas that are offensive to religious people with them i.e. evolution, only share what they can relate to and understand.	X					X	Emotional Sensitive topics Fear
Community need to be aware for an informed public response -some communities do understand -scientists must not overstep boundaries	X					X	Moral obligation

-original crops must not be replaced							
Stigma attached to people who manipulate nature						X	
Some GM food harmful, some safe and palatable, nutritious and easy to grow -feed more people but don’t know future effects Gain popularity because of cost and quality				X			
Huge chickens				X			Misconceptions
GM foods: The same as other foods just different in how they are produced The same as other foods except enhanced -Multiple advantages: increase yield; resistance to pests, nutritional value and increased growth rate; environmental tolerances; Growing population therefore needed; should not make adverse health complications; Good idea in developing countries but avoid monopoly of companies creating things like GM sterile seeds; - must not harm anyone;	X			X			
Method of GE dependent (i.re nuclear or chloroplast transformation) -nonspecifity of some of the technologies	X		X	X	X	X	
Not confident in GM foods				X	X		
Gov view: good because food for the people -uninformed -don’t care, no hype around the topic ; they don’t know that much; -should have education programs so people can express their views and concerns; -only interested in economy, not safety and benefits of people;				X		X	

Should encourage public education; To achieve service delivery, therefore if GM foods help curb hunger then they for it; Politics and Science should not mix; -Could mislead the public -must have enough knowledge and information and think about the public say as well; They are ‘for’ GM food and I think they should put a stop to it. -Need to be informed; -Spend more money on Biotech research in the country							
Uncomfortable : animal testing, unfair and unethical -injection of livestock to produce growth or milk production; -Genetic modifications to stem cells -the fact that bacteria and fungi are involved -The principles of food biotech; Testing of GM viruses on insects; Cloning animals, -Products tested on animals; -Modification of food which may cause illness; use of steroids to make poultry grow quicker;			X			X	
Caution exercised					X		
Access to biotechnology research on Internet -implemented with an emphasis on helping people and making money	X	X					
Interesting how genes can change resistance of plants to viruses or insects	X						
Teaching and Learning Biotechnology							
Interactive summaries; PowerPoint containing structured notes and diagrams with handouts on	X	X					

the internet; tutorial tests can motivate when do well;							
Practical laboratories allow for the application of skills and theory learned, enables visualization; seeing and observing helps with understanding, and remembering; -provides hands-on skills, and helps with imagining the concepts in the theory ; -application of theory -helps with employability	X	X	X				
Understand: when can explain the concepts to someone else and can help someone else; -explain at home to mother in an understandable way explain to layman); Discuss it with others; Writing an essay and report Application of theory in real life situations When it makes sense When do well in assessments; -when can visualize what happens and understand the steps involved; make my own examples	X	X	X				
Difficult aspects of biotechnology: volume of work, -involvement of other subjects e.g. genetics, microbiology, biochemistry and statistics, chemistry parts; molecular aspect, procedures used are complex and not everyday type; journal articles are hard to understand (weird long names and structures e.g. microbe names genus and species and enzymes); Bioreactors; vastness of new concepts and ideas - practicals only cover portions of processes. Terms difficult to remember and meanings;	X						

-practicals do not always work; -experiments sometime difficult to follow and understand -challenging to create theories to explain observations/concepts							
Cross-border teaching: -diverse range of ideas -different research expertise -exposure to opportunities in other parts of the world -speak good clear English, Accents are hard to understand -New ideas and thinking -other countries have access to cutting edge research and technology -other views on our material -widen knowledge capacity -takes out bias -only if expert in their field and have latest information -only if we can be employed in their country -not really necessary Wits has ample biotech lecturers -Other biotech focuses – show application in their country - to see if we on par with foreign international students, if our knowledge is comparable to other students in the world. -broader spectrum of knowledge -other ways of applying biotechnology, different perspectives -innovation globally helpful -view subject on an International /worldwide level	X	X	X				Perception that better skills and knowledge from outside and access to more

Biotechnology should be context specific (south African) because it addresses issues related to our communities and to benefit the country.	X	X	X			X	Moral obligation African solutions for African problems
Biotechnology Courses							
Biotech topics most enjoyed: Biotech of fungi and algae (real life processes) –bacteria and fungi used in industry; -GE applicable in the real world; Plant genetic engineering Bioremediation(to prevent further damage to the earth) biofuels (alternative fuel in the world); waste water management; biotechnology applied to environmental problems; -protein biotechnology; -prokaryotic genetics and their evolution	X		X			X	Moral obligation
Biotechnology bright future – will be around for long time -solves the world's problems without harmful consequences; -microbial food security concepts are practiced in real life – how food is made using microbes and how it becomes spoiled-affects the food industry – affects the economy	X		X				
Experience of real biotech:Engineering of algae to produce bioenergy; PCR amplification; plant tissue culture ; fungi taking up waste from the environment- (bioremediation and biodegradation); inserting piece of DNA into bacterial vector, amplifying it and transfecting human cell lines; Microbial food security – identifying pathogens in food; assessment for food security applied in industry;	X	X	X		X	X	
Community must be informed	X					X	Moral obligation

Pursuit of knowledge should be more important than public opinion and personal beliefs; -Good understanding of biotechnology is necessary to make it a good field	X			X		X	Solutions
Field trips and hands-on practical laboratory experience -beer brewing -water purifying plants	X	X	X				Solutions

Table 6: Summary of analysis of Honours Learner Questionnaires (WITS)

Conceptions	KNOWLEDGE	SKILLS	APPLICATIONS	AMBIVALENCE	RISK/HARM	ETHICS	Notes
Biotechnology Background & Meaning							
Many different processes that make up the 'bigger' picture	X		X				
Biotechnology is the bridge bringing technological era and green era together	X						Biomimicry
Few people embrace the topic and do the experimental work and there is too much debate	X						
Negative press and new technology threatens the older generations -Alien concepts -Public uninformed	X					X	Misconceptions
Risk to the environment					X		
Do not want to be associated with GM foods but from scientific and economic point of view they are a sustainable option.				X			
Honours projects at Wits access to latest	X	X	X				Solutions

research and it is implemented.							

Table 7: Summary of analysis of Focus groups (WITS)

Conceptions	KNOWLEDGE	SKILLS	APPLICATIONS	AMBIVALENCE	RISK/HARM	ETHICS	Notes
Biotechnology Background & Meaning							
Prefer that everything is taught in English English wording hard to understand -a lot of interpretation -2nd language takes long to translate back and code switching doesn't always help because English words are shorter -English idioms easier than zulu Hard to internalize words that not zulu	X	X					
English is the language of science -science is hard to interpret and English of science is hard to interpret	X						
Many questions in question papers can make up marks for questions understand best							Solution
For quite a number Medicine was 1st choice -some still want to be a doctor - always wanted to be a scientist, then	X	X	X				

wanted to medicine but back to science -want to find a discovery cure for AIDS especially since in home country Congo, many orphans because of AIDS -But with biotech can help a lot of people by discovering a drug Second choice = microbiology; industrial side -basically told to do a BSc at registration, wanted to do geology, no space							
Biotech can help to leave a legacy -be remembered for something	X						
Biotechnology provides treatment Provides food (Gm foods) and vaccines -But can have side effects			X	X	X		
Gel electrophoresis practical made me interested in a BSc.	X	X					
Medical microbiology -want to be a pathologist	X		X				
Priest, but religion is unexplained so turned to science for knowledge -the link is that priests are clever as are biotechnologists	X						Priest = clever like biotechnologi st Respect
Like the practical applications and being able to explain why the bread goes green for e.g.	X	X	X				Explain daily occurences
Cure for cancer	X	X	X				
Want to find out what is wrong with my ill mom -Want to find a cure for HIV/AIDs -Want to discover things	X		X				
Biotechnology skills are exciting and the same	X	X					

are used in genetics, microbiology and biochemistry							
Applications of Fungi new to us and so interesting	X		X				
Interest in how to make beer -play with molecules - all about the cell	X		X				
Practical laboratories help understanding and convince of concepts that were not really believable -they help formalize the literature from lectures	X	X	X				Seeing is believing
Do not enjoy animal testing -do not approve of growing proteins useful to medicine in animals Do not like testing drugs on animals should use humans for e.g. HIV/Aids drugs tested on HIV/AIDS positive individuals awaiting death sentence. -Should on rats and mice that are specially bred for that -computer based simulation - but humans do not respond in the same way -ethics should protect animals already been so useful in helping cancer research			X	X	X	X	Emotional
Students all happy to eat GM food, but parents (older generation) are not because according to the students it is their religious beliefs and they see it as scientists playing God, and because of believed health ramifications and perceived increased obesity				X	X	X	Misconceptions
Science is cruel -must have an ethical side	X		X	X	X	X	

Invention for people	X	X	X			X	Moral obligation
Drug discovery Gene therapy	X	X	X				
Gene therapy – therapeutics to help people	X	X	X			X	Moral obligation
Do not use animals for human benefit , but use them to grow organs while alive				X			Students do not really understand how animals make a contribution to GE. Misconceptions
Justified reasons for research						X	
Helps with acid mine drainage -food production -drug design	X	X	X		X	X	
Scientists need to understand concepts and find solutions	X		X				Moral obligation
Students take what they learn in biotechnology home e.g. check disinfectants for antimicrobials used as do not always contain the correct products to work properly -And allowing dishes to air dry without using a cloth to dry them	X	X	X				Moral obligation – teaching Moms about hygiene.
Students do not bring their cultural or traditional practices to Wits	X		X	X		X	Collateral learning
Cells sometimes hard to understand and picture e.g. cells moving in a petri- dish is actually possible	X	X	X				Seeing is believing

Good control in biotech experiments; -no biohazards or weapons produced -be careful of mutations -artificial bacteria	X		X	X	X	X	Misconceptions Mutations could be good
Visible in everyday life e.g. washing hands in cold water and soap vs hot water and soap.etc.etc.			X				
Opened up my thinking – better prepared for life	X	X	X				
Biotech subjects genetics and biochem -learn lots of skills	X	X					
Analytical skills	X	X					Analysis
Christian therefore more open-minded about learning science						X	
Culture and religion must be looked at together -biotech and science do not go against them or my conscience. Science helps religion have a place -The intricacy of science is a confirmation of God	X					X	
Science can only be shared with open-minded people	X						
Completely religious people leave their ideas outside the science class	X			X		X	Collateral learning
Can only discuss what you learn in Biotech with open-minded people and people willing to change their mind	X			X		X	
Science field ask 'why' about everything	X			X		X	

-ignore superstitions and old wives tales -can't talk to people who don't question the Bible							
Only limit in biotechnology is your imagination	X						Imagination
Biotechnology is empowering and biotechnology students get a sense of superiority over other students -People think we are clever if we study these courses -we are smart because we analyze	X						Empowering Superiority
Some people worry about the experiments we are doing					X		Negativity
People think we have the answers to all their questions because we are doing a BSc.	X						
Biotechnology is always developing.	X	X	X				
In SA because we do the experiments ourselves without using kits and machines Like they do in England. We understand the background and we can make use of "home-made" alternatives and still get results	X	X	X				
The general public need to believe in us.	X					X	Moral obligation
White students want to leave the country once they have their degrees because of BEE they won't get a job				X		X	
Sangomas do not believe medicine costs money				X		X	
Sangomas just use herbs without knowing the side effects Sangomas influence the communities so we need to work with them	X			X		X	

Traditional healers (Sangomas) regarded with respect -but we now with biotech knowledge question what they pout in their concoctions - we have open minds and because they are respected people in the community we don't step on any one's toes but do not take what is given to us. -ancient methods are more dangerous -We need to play a role to get a balance bacause our scientific knowledge should guide and we should try to work together. - we should make the transition -promote what we know not criticize. -eventually it will all change as the older generation die off. -it also depends on whether you believe it works or not. -evolution knowledge does not get passed on Concoctions for HIV etc don't know what it is sometimes cures one thing but leads to something else. -people just believe what they are told and that that is how it must be.	X		X	X	X	X	
Sangoma are used because of family background. Grandfather went, therefore father and brother go. A Zulu sangoma is a sham but it is difficult to convince the village not to use them, therefore we should work with them.	X			X		X	Indigenous knowledge
Disappointed in the Government because they denied that HIV caused AIDS. Famous words like "eat beetroot" and 'take a shower" makes them very angry	X					X	

Lecturers must be very sensitive about how they introduce concepts and they should not say things they have not thought about	X					X	
Liked writing scientific reports and reading and analysing scientific papers.	X	X	X				
Check grocery products for additives such as aspartamine not for GMOs	X		X		X		
GMO acceptable -just should not have side effects and anything unforeseen				X	X		
Pharmaceutical companies should support scientists.	X						
People fear cloning because it is unknown to them	X				X	X	
People with no background can't understand.	X						
Concepts such as evolution that are not proven are hard to believe -People can't understand evolution therefore don't believe and therefore we can't convince Initial of evolution that is fuzzy.	X			X			Scientism
Also hard to understand or believe something you can't see e.g. DNA is invisible.	X						Seeing is believing
Science we learn is acceptable as long as we are all like minded, doesn't matter what religious group -then can put everything together and accept and try and understand -need to grow together and develop and learn from each others views. This even enhances your knowledge about God.	X	X	X			X	Moral obligation
Background effects how you learn – like if lecturer starts out by knocking that God	X					X	Respect of each other's

created the earth, then you can't learn from them							ideas Solutions
Traditional knowledge should be used in biotech programmes – negotiations with communities	X		X			X	Solutions
No-one in FG2 or FG3 wants to stay in SA but if do would work on traditional knowledge inclusion in programmes, with natural resources rather than artificial resources				X			Students leaving country
Have Basic cell information – then apply what learn	X	X	X				Moral obligation
Big gap between school and university	X						
Applications very important; clear and definite information with relevance and meaning produced and knowledge ; science changes quickly	X	X	X			X	Moral obligation
Information from other countries can be included as extra to spark ideas -However, learn more from own choices	X		X				
BSc in biotechnology gives skills and you just need imagination -Work under pressure	X	X					
GMO use is dangerous - student hypothesize that there is a change in growth patterns in children depending on GMO intake -In Congo food is natural - in SA all food is GM; Chickens grow in 2 days , girls mature faster and are larger (might just be Jhb not rural farm girls) -KFC chickens no legs and no beaks just mass produced body					X	X	Misconceptio ns Misinformed
Older generations have problems with GMOs	X					X	

because of stronger cultural beliefs (like when do not eat beef or pork- weary that GM with a beef or pork gene)							
Older generation and religions such as Jehovahs Witness not open to medical operations and help	X					X	
Evolution not believable -learn it but don't believe it -Microbial evolution more believable because oif antibiotic resistance development etc.but for humans too complex. -Some try to keep an open mind. - bible principles don't make sense as could not have managed all the biodiversity in the world on the boat -Practicals can help change your belief, as can see microbes everywhere and you see the growth on plates.	X		X	X		X	Collateral learning Literal understandin g
Sometimes problem to take science knowledge home as parent doesn't believe you	X					X	
Genetic practice on humans is not good	X					X	Misconceptio n
Biotechnology can help explain common daily occurrences and explain why we have the genes we do and can help with drug discovery	X		X				Solutions
Excursions to industrial labs Hands-on laboratories help with understanding and visualization and helps acquaint student with techniques and background.	X	X	X				Solutions
Believe what is acceptable to you because we all understand in different ways and have different beliefs	X					X	

Biotechnology Background & Meaning							
No idea of biotechnology when came to university Learning about it – developed interest -More learning about now started worrying about it esp GM food	X				X		
Manipulating microorganisms Application in Industrial processes	X		X				
100% acceptable- Do not have strong beliefs in different things -understand what it's about -there is proof behind it	X					X	Scientism
Less acceptable -Community beliefs -lack of understanding of what it is -lack of information -religious people think it's Scientists playing God (especially when it comes to cloning)	X				X	X	
Challenges like sorting poverty is not playing God. realistically there is poverty and biotechn can help, but at church believe if people weren't greedy there would be enough for everyone -I ask God for solutions and science is a solution.	X			X		X	
Scientists should test their GM modifications in themselves and humans -improve soil for better produce	X					X	
Would not tell the community: Testcrossing fruit flies to study genetics and genetic linkage (wild type and mutations)	X			X	X	X	

-fungi (seen as living organism in communities) play a role in industry -worried that they do manipulations on humans underground – FDA not aware of all research -hesitant to tell how some foods are made – especially sausage so many microorganisms in sausage -We ingest many microorganisms naturally -Told Mom a glass of milk a day is 5L of pus a year, so she stopped drinking milk -friend over washes her hands to avoid bacteria							
I am scared of what we don't know, but what we don't know can't hurt us				X			
Labeling is important - so people can make a choice -awareness is important -especially to scare -info should be clear and concise with simple language and easy to understand (not jargon) Clear on cigarette packets but people still smoke	X			X		X	Moral obligation
Students unsure if make potato in the lab?				X			Misconceptio n
Bacteria used to insert a gene of interest -grow cells in the lab Do not agree with above/love the idea	X			X			
Biotech practices must not have negative effects	X		X		X		
PGE -more food	X		X	X			Communities generally know how to

-help alleviate poverty -medicines for the poor people -train in basic processes and growing GM crops (sort unemployment) -community could become self-sustained							manage sustainable crops
Biotechnology processes should not be for financial gain or for political reasons	X		X	X		X	
Biotechnology knowledge helps to prevent the early deaths of cloned amimals like Dolly the sheep and Mphuti the cow.	X	X	X			X	
Find out the different ways scientists can make life easier and how to do it	X	X	X				
Its about green fuel			X				
With more knowledge about what biotechnology is about makes one less suspicious	X					X	
Not acceptable in communities -traditions and no background knowledge Traditions will not accept recombination of genes i.e. this does not happen and does not have an outcome on the phenotype.	X			X		X	
Acceptable because have the knowledge -when started varsity lots of publicity around cloning and I had narrow view Knowledge has broadened my view	X						
Don’t believe in evolution -keep science and religion separate				X			
Talk to my family about anything, but they just don’t understand -they find it interesting -but can’t change religion and I wouldn’t want to	X			X		X	Interesting Would not want to change religion (I think it’s

-the dilemma between science and religion: science makes sense; religion doesn’t - we can use science to prove if something exists. -science supports religion Science and religion overlap on some levels but different on others.							because it gives people hope) Scientism vs skeptic-cism
Religion says God gives to us – He gave us science to find out things -he created everything				X			
Worried about long term effects -genes added over time -are GM plants that nutritious -will GM foods make superhumans?	X				X		Doubt
Ok if only plant genes in plants	X	X			X	X	
Uncomfortable with biotechnology practices- religious reasons because the ethical issues are that they change what they believe in -we also do not always know what we are buying -cloning body parts problem – do not want a grown heart				X			Lack of necessity maybe… I think people would accept a grown heart if really needed one to survive, just my hunch from outcomes of focus groups
Genetic knowledge can explain things like albinism; homophobia -this knowledge can stop the stigma of believing the child is bewitched in the case of albinism and discrimination in the case of homophobia -teachers need to be taught the	X		X			X	Misconceptions Perceptions Traditional beliefs

discrimination and mismanagement starts at school							
Medical research for treatments and cures -Improves the health of people			X				
Broad focus -can make a career out of it			X				
In my muslim background – genetic beliefs are accepted but not evolution- I just explain the could happen just as people adapt to situations so we adapt to our environemt -I couldn't change the ideas but I can explain what I have learned and they would listen -I don't make them question what they know.	X		X	X		X	
In Hinduism we believe a foetus is only alive after 5 months, whereas in genetics it is after fertilization -the better way to explain it is development is happening from the beginning and the soul enters at 5 months.	X		X			X	
What we learn not 100% accepted in our communities: We are allowed to in fact encouraged to marry cousins (muslim and hindus) which is not encouraged in genetics -We understand this and we do see the results of recessive genes coming together in our families (a lot of deafness and heart conditions), I have explained it to my family. -in Jehohovah's Witness family no blood transfusions or organ transplants	X		X			X	
Instead of trying to change communities' beliefs we should work within them. As scientists we should find solutions -need proof to show people then will accept	X					X	Moral obligation scientism Solutions

change and not remain stuck in their ways.							
Hesitate to tell people in my community: ingredients of soya sauce or meat products (although shouldn't be problem as it is fermented, soaked and processed) -fungal substitutes in certain products (Even though vegetarians- fungi are considered alive) I wouldn't be able to tell them even though I should	X			X		X	Protection of facts
Long term effects -but need to use and test to find out	X						
Field trip to breweries -cultural religious problem - family dilemma - helped by it being compulsory and essay question included. -other Muslims don't allow kids to attend university because of evolution and students that drink alcohol	X	X	X			X	
Alleviate poverty -achieved by growing GM crops that grow faster, have more nutrients and a larger yield and improve employment	X	X	X			X	
Manipulating organisms for our benefit and own use and use in industry , pharmaceuticals	X	X	X				
After years of studying science we finding things out -Applying the knowledge and its encouraging as it is directly applicable to what's going on.	X		X				
Trust that laws and limitations are in place						X	Trust
Open to accepting because of ancestral and Buddhist influence	X			X		X	

Science and religion incorporated in a logical way	X			X		X	
Biotech enforces beliefs as a Christian- makes my faith more concrete	X						
Societies are predictable how they develop -fear of change and anything that is complicated -"crazy" new ideas become normal	X			X			Evolve to accept all ideas
Students not interested in having ethics and moral information added to courses -boring				X			
Trust in people doing the experiments = and trust the the anti groups keep people aware of risks	X					X	Trust
Uncomfortable with anything to do with animals -exsanguination of rabbits and chick embryo dissections - just use cell cultures in vitro and even grow organs to do testing				X		X	
Model organisms – good living conditions	X			X		X	
Biofuels –different energy sources			X				
Modifying the human genome is a problem- but not modifying plants						X	
In vitro fertilization -choosing traits in developing embryo Things to do with sexual reproduction crazy -choosing sex of baby fine with one others completely disagree with it. – having kids is a blessing and gift -you should not be able to change a trait	X	X	X	X	X	X	

- accept what you get							
Biotech effects people directly -general fear is lack of knowledge	X				X		
Just because something is inconvenient does not mean it is right or wrong -It is about the learning and understanding the human race -we are still learning about life	X						
Must keep a balance -Do not have to accept something just because science says it is so -need to learn it before you can form an opinion -don't change when you are in the science world –find a balance and form an educated opinion	X						Anti – scientism
Try to explain biotechnology from a biblical and scientific standpoint because parents very religious and are not going to believe the information we present to them esp evolution-they narrow minded - to explain to them you should use layman's terms and make it very practical. - agnostic parents (acknowledge a higher spiritual power) are open-minded and think it's great because there is not a set of rules that need to be reconciled with science –just go straight into it without all the background	X					X	
Biotechnology must not interfere with the perception of your biblical studies and it must not complicate it. I believe everything I learn at University but not evolution.	X			X			Collateral learning
GM foods are exactly identical to what's there already and no sides effects But what if you only find out there are	X			X	X	X	Students not showing much genetic

side effects 100 years later -the WHO is in control -the point is to weigh out the pros and the cons -What if someone in 10 years time finds a new disorder the result of GM -what if GM plant with too much genetic material adds to our genome and there is some evolutionary consequence -how do we know the genomes are stable. - difference between 6 normal apples to 6 GM apples. -worried about the chain effect which happens if we change something then in a later generation that changes something else.in other words this change affects something else and could have a serious consequence over time							knowledge - Collateral learning
Knowledge is unsettling – like knowing they use fungi and bacterial cultures in food can make one paranoid –aeroplane food with bacterial cultures. -just an association because you associate bacteria with illness , you don't think about good bacteria -knowledge in the wrong hands , biological weapons -if make a super virus or falls in hands of a sick dictator like Hitler. -capitalists take care of the market	X			X	X	X	
Sort out poverty and starvation using GM foods -help petrol crisis -cure disease through medication	X		X			X	
Initially not sure about it but learned more and become interested esp in PCR –cloning pieces of DNA	X						

-Opened up a whole new world to me							
Community disagrees with it -because of religion - and they have issues with it - individuals in the community disagree with it not the whole community -it's the lack of understanding and it's ignorance -but if able to explain About it and how it works they seem to accept it, if they understand the information -community disagrees with it because it is not proper and this is because of lack of understanding	X			X		X	
Great because of climate that is changing – can help agriculture	X		X			X	Moral obligation
The ethics code that goes with biotechnology should be made public						X	
Where will it end -already see enhancers rife in sport and even politicians take them to make themselves feel better. Where is it going to stop? What is it going to lead to?					X	X	Students not that into progression or Change
Everything has potential to help or destroy. It depends on how you use it. It is not biotechnology that's the problem-it is war itself. that is harmful	X				X	X	
Food availability -cure disease -biofuels-drop the oil price and eTolling			X				
Need to use biotechnology skills to make more plant biomass available , cows and animals break down enzymes in grasses for	X	X	X				Solution

nutrition , we cannot – but if we could find and use these we would help human consumption and there would be more food available							