# Sustainable development as a threshold concept:
# An investigation into chemical engineering students' knowledge

By

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# Abstract

The increasing global awareness of the concept of sustainable development is making more people worldwide aware that current human behaviour is unsustainable. Some of the key challenges are massive population growth, climate change, large areas of deforestation, diminishing non-renewable resources and overharvesting of renewable resources. As the challenges intensify, more people are realising that new approaches to resource management, economic activities and development are required. To face this environmental crisis, a new education is needed. Because engineering has a considerable impact on the environment, it is therefore required that engineers play a crucial part in protecting the environment. In response to this, accreditation bodies worldwide are requesting the inclusion of sustainable development in undergraduate education. Most accrediting bodies are specifying that sustainability competence should be a requirement for graduation in engineering degree programmes. The Engineering Council of South Africa (ECSA) requires engineering students to be able to assess the benefits and impacts of design from an environmental, legal, social, health and safety perspectives. Whilst the concept of sustainable development has gathered momentum in recent years, our unsustainable practices imply that insufficient progress is being made to change from unsustainable to sustainable pathways. In order to facilitate better integration of sustainable development teaching within the engineering curriculum, it is essential to understand what students know and the conceptions or misconceptions they have about sustainable development.

Several prior studies investigated the integrating of sustainable development in engineering education and have also explored what students know about sustainable development. This research thus follows previous work by Carew (2004), Davis and Wanous (2007), Penlighton and Steiner (2007) and Azapagic et al. (2005). These studies aimed to investigate the sustainability conceptions held by engineering students and to assess their level of knowledge on sustainability concepts. The findings revealed that the level of knowledge is poor and engineering students had varying ideas on what sustainability is.

Following on previous studies, this research seeks to explore the different dimensions of sustainable development as understood by engineering students and to establish if the learning of sustainable development can be characterized as learning a threshold concept. The

research investigates students' experiences of learning about sustainable development. The data for this study were collected through individual in-depths interviews with sixteen purposefully selected postgraduate students and a survey that was completed by twenty-six final year undergraduate students, all from the Chemical Engineering Department of the University of Cape Town.

The research findings suggest that five qualitatively different dimensions of sustainable development exist among chemical engineering students. These different facets of sustainable development as understood by the students are an indication of how complex sustainable development is. The findings also reveal that sustainable development is a threshold concept and that each student experiences the learning of sustainable development differently. There was evidence to imply that the concept of sustainable development is transformative, integrative, irreversible and troublesome. While there was no substantiation from the data analysis that the concept of sustainable development is bounded, this is expected as a very part of its nature and not a problem as threshold concepts are not necessarily bounded. The results also suggest that the learning experience is different and the way students navigate the liminal space differs. This all has major implications for engineering education and poses a challenge of how best to teach sustainable development and thus produce graduates with an appropriate awareness of sustainable development.

# Statement of originality

I, Lesley Sibanda, hereby declare that the work contained in this thesis is my own work. This thesis contains no material previously published or written by another person except where due acknowledgement is made in the text. Guidance was, however, provided by my supervisors. The conclusions are based on my own understanding of the literature and results of the qualitative studies conducted.

Signed ……L.Sibanda

Lesley Kudakwashe Sibanda

Date ……31 August 2011

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# Chapter 1 Introduction

## 1.1. The current environmental crisis

The environment is under threat. Accelerated population growth, climate change, large areas of deforestation, diminishing non-renewable resources and overharvesting of renewable resources are some of the challenges we are currently facing – and they all seem to be getting more intensive as more societies industrialize (Bolea & Grau, 2004). Human behaviour is currently unsustainable. The inefficient use of resources to support unnecessary and excessive consumption is leaving too little of these primary resources available for those who wish to develop, now and in the future. The wastes generated from production and consumption processes exceed the ecosystems' assimilative capacity at local, regional and planetary scales. Failing to observe limits imposed by the availability of non-renewable resources, regeneration rates of renewable resources and absorptive capacity of ecosystems is impacting negatively on the quality of the global environment and the quality of existence for the diverse range of species relying on it.

This current situation of unsustainability requires new approaches to development, economic activities, resource management and environmental protection. To face this environmental crisis, many have realised that a new education is needed. A global response is being led and coordinated through the United Nations Decade of Education for Sustainable Development (UNESCO, 2010). As the survival of human society and the environment depends heavily on the learning of new behavioural patterns and technological responses, fundamental solutions require a transformation of educational systems. This change within the educational paradigm should "embrace the social and natural environment as a whole interrelated by itself and should link the models of growth with an integral development sustained in a healthy atmosphere" (Bolea & Grau, 2004, p. 3). Engineering activities have not only significant impacts on the environment but also mediate individual and social processes, and so it is only right that engineers should engage with such questions of education for sustainable development.

## 1.2. Overview of the literature on sustainable development

The concept of sustainable development is perhaps one of the most contested concepts in literature (Gallopín, 2003). Despite the fact that the term sustainable development has gained familiarity and is widely used all over the world, it lacks a uniform interpretation and there are various conceptions and definitions of what it is. Whilst many might consider this a problem, Carew and Mitchell (2008) suggest that the many conceptions are to be expected because the concept is multifaceted and abstract. They further state that the many conceptions arise from the fact that sustainable development involves both scientific facts and ethical or moral issues. On the other hand, the multitude of opinions on sustainable development may be suggestive of the high-stakes involved (Gallopín, 2003). To start to unpack the idea of sustainable development in the context of this dissertation on its learning in engineering education, I will make use of the conventional definition given by the United Nations' "World Commission on Environment and Development" (WCED) in 1987, commonly known as the Brundtland statement, as a starting point:

> "Humanity has the ability to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987).

Despite criticism that the WCED definition of sustainable development is vague and ambiguous, it has made a great contribution by emphasizing the significance of sustainable development (Daly, 1990) and has been highly influential in developing a 'global view' with respect to the future of our planet (Mebratu, 1998). This WCED definition implies that sustainable development is a process of change in which the exploitation of resources, technological development and institutional changes are in line with both future and present needs (WCED, 1987). Whilst this definition of sustainable development prominently called for limits to physical growth, it also primarily called for development particularly for the poor (Mebratu, 1998). It emphasises that environmental concerns should be addressed, though not at the cost of the aspirations of the poor nations to overcome poverty and attain decent standards of living similar to those of the more affluent countries (Hattingh, 2001). The WCED

definition adopts an anthropocentric approach, often referred to as a softer approach (Goodland & Daly, 1996). It basically implies that natural capital can be converted to human or financial capital, above certain critical thresholds. This view describes sustainable development as improving the quality of life of humans and is mainly concerned with the eradication of poverty and fair distribution of resources (Hattingh, 2001). Goodland and Daly (1996) describe the other approaches to sustainable development and state that sustainable development can fall under four degrees namely weak, intermediate, strong, and absurdly strong. They further state that the degree is dependent on how much substitution occurs among the different capitals (Goodland & Daly, 1996). Based on this, the anthropocentric approach is viewed as weak sustainable development as resources are exploited to satisfy human needs. A strong degree of sustainable development which is supported by ecocentrists (nature-centered people) argues that nature should be valued for its own sake (Goodland & Daly, 1996). Within the ecocentrists' view, no capital can be changed into another form of capital indefinitely and the absorptive and regenerative capacities of the natural system must be respected (Goodland & Daly, 1996). The definition given by Goodland and Daly (1996) describes sustainable development as "development without growth in throughput of matter and energy beyond the regenerative and absorptive capacities of the ecological system" (p. 1002). They state further that the dominant paradigm of economic growth is unsustainable, as it destroys the very health of the natural ecosystems from which economic resources come.

Whilst the dominant conceptualization has been to view the economic, social, and environmental spheres as independent of each other as shown in Figure 1, Mebratu (1998) argues that this should not be the case. He states that the depiction of sustainable development as three overlapping circles suggest that these aspects of sustainability are independent systems that must be treated interdependently (Mebratu, 1998). The central zone of overlap represents concurrent environmental, economic and social sustainability. The ultimate goal of sustainable development is to successfully integrate these three aspects in a non-threatening manner. However, this view of sustainability is limiting because the economic and social aspects have never been separate systems independent from the natural universe (Mebratu, 1998). Mebratu (1998) captures it more realistically with his 'cosmic interdependence' model depicted on the right of Figure 1.

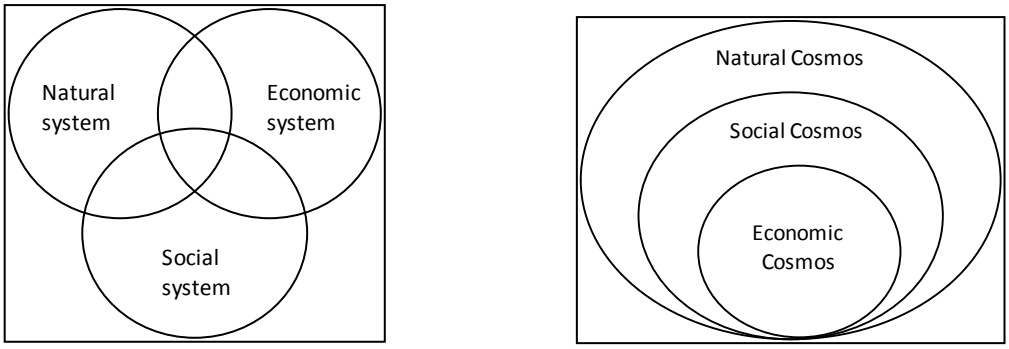


**Figure 1: The dominant model (left), and cosmic interdependence model (right) - conceptualizations of the world (adapted from Mebratu, 1998)**

The interdependence model makes explicit that while the natural environment can exist without human social and economic systems, the reverse is not true (Mebratu, 1998). This interdependence model represents a systematic approach to sustainable development and suggests that an understanding of the systemic influences and existing inter-relationships between the natural, social and economic spheres is central for creating sustainable human systems.

It is now generally accepted that sustainable development should not be restricted to mere economic growth but that natural capital and ecological integrity should also be preserved. Sustainable development can only be achieved if rates at which renewable resource inputs are harvested, are kept within the natural system's regenerative capacities, whilst the rates at which non-renewable resources are depleted should be equal to the rate at which sustainable substitute resources are developed (Goodland & Daly, 1996).

Many authors, e.g. Carew and Mitchell (2002) argue that sustainable development involves making appropriate changes to decision-making processes and requires a holistic approach. This implies that sustainability is about considering the world as a whole, made up of embedded and inter-connected systems. In current thinking, sustainable development is therefore essentially about integrating the economic, environmental and social considerations into all decision-making and about ensuring equity, poverty alleviation and considering the needs of future generations. For sustainability to be achieved it is essential that there be an interaction and connection between society, the environment, and economic or industrial development (Huntzinger, Hutchins, Gierke, & Sutherland, 2007). However, achieving this balance

is not easy and requires an adequate understanding of the impacts our activities have on both the society and industry impact the environment and also how current activities impact future generations. There is therefore a significant need for increased knowledge and consciousness sustainable development issues (Huntzinger, et al., 2007). It also requires engineers to work together in partnership with other professionals and the public for the common good (Clift, 2006).

## 1.3. Engineering education and sustainable development

The emergence of engineering has always been closely connected to development (Lucena & Schneider, 2008). Engineers are influential and have always been seen as agents of change, often with the primary aim of "altering nature into a predictable machine that could be easily controlled for financial gain and to showcase superior technology" (Lucena & Schneider, 2008, p. 248). The evolution of the engineering disciplines, tied into the paradigms of the societies which they served, did not regard environmental sustainability until very recently, but was motivated by economic and political development (Lucena & Schneider, 2008). The overriding concern in most engineering education programmes was that engineers be competent in engineering science as opposed to looking at social and environmental concerns (Lucena & Schneider, 2008). Since the 1980s and the publication of the Brundtland report, there has been a realisation that the engineering profession plays a pivotal role in the creation of sustainable societies from local to global levels (Bryne, Desha, Fitzpatrick, & Hargroves, 2010).

The growing awareness of the concept of sustainable development has led to many engineering programs incorporating skills, concepts and attitudes needed for sustainability into undergraduate university courses (Carew & Mitchell, 2008). Accrediting bodies around the world are requesting that engineering students be trained on how to integrate societal and environmental concerns into their professional practice (von Blottnitz, 2006). In South Africa, the Engineering Council of South Africa (ECSA) has published their expected exit level outcomes for engineering graduates. Amongst others, ECSA requires that engineers should be competent in engineering design. In particular, engineers should be able to assess the impacts and benefits of their design from different perspectives i.e. social, health, environmental, safety and

legal (ECSA, 2004). ECSA also requires that a graduate within the engineering field be conscious of the impacts of engineering activities on both the environment and society (ECSA, 2004).

In line with increasing global consciousness and the importance of sustainable development, a total of eighteen chemical engineering institutions signed the London Communiqué in 1997. They pledged to work together "to make the world a better place for future generations" (Batterham, 2003, p. 2169). In 2001, the South African Institution of Chemical Engineers (SAIChE) together with nineteen other chemical engineering institutions signed the Melbourne Communiqué. By signing the Melbourne Communiqué, these institutions committed to using the skills of chemical engineers to improve quality of life and advance social and economic development. They also pledged to protect the environment through sustainable development (IChemE, 2007). Later in 2007, the Institution of Chemical Engineers (IChemE) drew up a strategic plan aimed at moving towards a sustainable future titled "A Roadmap for 21st Century Chemical Engineering" (IChemE, 2007).

The inclusion of sustainable development into engineering curricula is essential in successfully tackling the problems that have resulted from unsustainable practices. Clift (2006) states that although sustainable development is a transdisciplinary issue, engineers are essential to solve these problems. Further, he is of the view that chemical engineers especially are central to achieving sustainable development as they have to understand and manage complex systems. This he argues is because the idea of systems thinking has been central to the chemical engineering practice (Clift, 2006). He argues that system-based tools must be developed to manage the environmental impact and performance of human activities (Clift, 2006). Engineers also have ethical and moral responsibility to design processes and develop products that do not damage the environment but that are instrumental in creating sustainable societies (Bryne, 2009).

## 1.4. Investigating students' understanding of sustainable development

The emergence of new accreditation criteria for engineering programs has seen many higher education institutions incorporating sustainable development into their curricula,

research and daily operations (Lozano, 2010). Despite the numerous efforts by these institutions, sustainable development is still considered a novel idea in most universities. Because the concept of sustainable development is interdisciplinary, integrating it into the curriculum has proved difficult. In the area of engineering curricula, Boyle (1999) states that since environmental issues were not traditionally a required module of the curriculum in engineering, most academics have very little education on environmental issues unless they were involved in the field or had a personal interest. Because of this, these academics might feel they do not have the necessary background to teach environmental issues and are probably not certain that environmental issues should be a component of their specific courses (Boyle, 1999). It is likely that the same argument applies to the incorporation of social issues, possibly even more strongly, whilst, on the other hand, economic (and especially) financial considerations were often part of engineering curricula already.

There is a reasonable amount of work that has been published on integrating sustainability and engineering education and some studies that have explored what students know about sustainable development, have been conducted. These studies have been reviewed and are discussed in this section.

Azapagic, Perdan and Shallcross (2005) did a worldwide study of engineering students' perceptions and knowledge of sustainability. In the study, the researchers conducted a worldwide survey aimed at assessing the students' level of knowledge and their understanding of sustainable development and related topics. The survey involved 40 universities based in Europe, South and North America, Australia and the Far East. It was also intended to quantify students' perceptions of the importance of sustainable development, and students' familiarity with environmental and sustainability concepts. The survey involved a questionnaire with 45 questions. These were divided into two areas; the environmental and the sustainability-related concepts. The students were asked to specify if sustainable development was important from both a personal and a professional level. The results of the survey revealed that the students' level of knowledge and the understanding of sustainability-related and environmental concepts were not satisfactory. The students were knowledgeable about high profile environmental issues, such as acid rain and global warming. However, there was a poor level of knowledge relating to 15 other aspects such as eco-labelling, industrial

ecology, intra-generational equity, the Kyoto Protocol, the ISO 14001, and the Rio Declaration. Most of the students claimed to have heard of the different concepts but could not explain these in great detail. Despite a relatively low understanding of sustainable development, most students recognized sustainable development to be either important or very important and expressed an interest in learning more about sustainable development. The responses obtained in this survey were similar over the range of different student groups that participated. However, a major limitation to this study is that it did not reveal what students actually understand about sustainability, as most of the questions asked whether respondents had heard of certain concepts or not. The survey results suggest that gender and the level of study have an influence, but highlighted differences between countries. Students in the Far East and Europe appeared to have the highest level of knowledge and understanding relative to their counterparts in Australia and America.

Carew (2004) conducted a study in Australia which involved a group of undergraduate chemical engineering students. The research was about what undergraduate engineering students might know, think and feel about sustainability. The study involved an open-ended question: "In your own words, what is sustainability?" This was intended to capture the conceptions on sustainability that were held by the students. The students were also asked to rate how well they understood sustainability, how relevant they thought sustainability to be to their future careers and how interested they were in learning more about sustainability. The students' responses were analysed using the SOLO taxonomy and the analysis revealed that there were considerable variations in the sustainability conceptions held by the students. The results also showed that students were not totally confident about their understanding of sustainability though they felt understanding sustainability would help them in their future careers. The students also revealed an interest in learning more about certain aspects of sustainability. These aspects were related to students' own actions as future engineers.

In 2007, a study to explore the views, attitudes and experiences of the teaching of sustainability held by engineering students was conducted by Penlington and Steiner within four UK universities. A total of 142 students completed a questionnaire whilst 22 students took part in focus groups. The questionnaire sought to obtain a measure of

the students' concern for the environment. It also aimed at "establishing the students' perceived level of knowledge of several topics relating to engineering design and sustainable development" (Penlington & Steiner, 2007, p.1). The students were also asked to point out which topics they had an interest to learn more. Subsequent to the questionnaires, the researchers held qualitative focus groups which were based on the questionnaire outcomes. The focus groups explored the definitions and understanding of sustainability and also the students' experience of the teaching of sustainability concepts. The results of the study showed all respondents were able to provide definitions of sustainability which ranged from specific to broad definitions. All respondents said that sustainability was very important and most responses strongly felt that sustainability teaching should be incorporated within the engineering curriculum. The responses also suggested that peers and the media played a significant role in their knowledge content, and both quantity and quality of teaching were criticized. Many students felt that sustainability was taught more like an afterthought and the lectures were not sufficient to convey the message. The key conclusion of this study was that there is a need for a deeper understanding of sustainability issues within the undergraduate curriculum.

Similarly, Davis and Wanous (2007) carried out a survey to determine the level of understanding of sustainable development among engineering students enrolled at Bristol University. The survey results indicated that students had relatively high levels of knowledge on topics such as renewable energy and waste minimisation. However, there was a relatively low level of knowledge for topics such as such as product stewardship and industrial ecology. Overall, the results suggest that the learning of sustainable development is a progressive process as the level of knowledge and understanding of environmental issues and sustainable development seems to have increased over the duration of study. Students in the final years (i.e. 3$^{rd}$ & 4$^{th}$) demonstrated higher levels of knowledge than students in the first two years of study.

The commonality in these studies is that the findings reveal that although students knew about sustainable development, their level of knowledge about certain sustainability topics is relatively low, especially related to the importance students afford to the topic. These studies also suggest that many facets about what sustainable development is and what it entails, are held by students. This would suggest that

improvements are required within higher education institutions so that engineering students are better equipped for their professional careers, ultimately to make informed decisions that incorporate sustainable development in their work. To do this, we need to address the problems that engineering students face when learning about sustainable development and look into ways in which they can learn more effectively.

## 1.5. Objectives of this study

Given the above, the main objective of this study is to gain insight into the different dimensions of sustainable development as they are understood by engineering students. To do this, the researcher intended to explore what engineering students understand about sustainable development and how they have experienced the learning process. Investigating what students know about sustainable development is imperative as literature (Carew, 2004; Marton & Säljö, 1976a, 1976b) has shown that what students understand and think about a concept influences the way they engage with learning of that concept. Carew (2004) argues that students' personal constructs are evidence of the way that they engage with and learn about sustainable development. Furthermore, the approach and attitude that a student takes during learning also significantly influences the quality of learning and as well as determines how successful the student is in grasping the concept (Carew, 2004). To do this effectively, it is imperative that theoretical literature on student learning needs to be reviewed and understood and this is undertaken in Chapter 2.



## 1.6. Overview of thesis

In this chapter, the problems that have arisen as a result of unsustainable consumption and production patterns have been discussed. A review of literature on sustainable development has also been outlined together with a brief history of its relation to engineering and engineering education. Studies that have been conducted on the learning of sustainable development within engineering education have also been reviewed in this chapter, and the study objectives were consequently outlined.

In Chapter 2, a review of the related literature regarding the theoretical frameworks of learning governing this study will be provided. The key frameworks discussed in this section are phenomenography and threshold concepts.

Chapter 3 outlines the methodology used in this study and provides a justification for the methods used during the data collection and analysis.

Chapters 4 and 5 give the detailed findings of the interviews and surveys respectively.

Chapter 6 provides the general discussion, which draws on the literature presented in Chapters 1 and 2. The implications of the study, together with recommendations for future study are given in response to the conclusions of the thesis.

# Chapter 2 Theoretical frameworks informing the study

To be able to investigate the various conceptions of sustainable development, it is imperative that we review literature about the way students learn and review the different research paradigms that might be useful in this research study. This study aims to determine the different facets of sustainable development as understood by engineering students. Thus to do this effectively, it will be necessary to adopt a theoretical perspective on learning. In this chapter a number of key theoretical frameworks are reviewed. The first sections discuss the phenomenographic theory which gave rise to 'approaches to learning' and subsequently to 'conceptions of learning'. The chapter then looks at threshold concepts which also arose from phenomenographic work and which are used as the primary framework to guide this study.

Phenomenography is a theory that arose from studies conducted by Marton and Säljö in the late 1970s at the University of Gothenburg in Sweden. Over the years, the phenomenographic theory has developed with widespread applicability in research into student learning in higher education (Barnard, McCosker, & Gerber, 1999). It is a "distinctive qualitative approach to understanding a broad range of phenomena" (Barnard, et al., 1999). Phenomenography has been described by Marton (1981) as "research which aims at description, analysis, and understanding of experiences; that is, research which is directed towards experiential description" (p. 180).

Phenomenography focuses on the different ways that people experience phenomena they meet in the worlds they live in (Ashwin, 2009). It "does not examine the conceptions held by individuals but rather examines the different ways in which a particular phenomenon is experienced by a group of individuals" (Ashwin, 2009). Phenomenographic research distinguishes between the first and second order perspectives. The fundamental difference is that the first order perspective describes phenomena as seen or experienced by experts whereas the second order perspective describes the phenomena as they are understood across the population (Barnard, et al., 1999). The second order perspective is therefore about describing people's experiences of the different parts of the world (Marton, 1981) from their perspective. According to

Booth (2001a), phenomenography is not prescriptive as the techniques used often vary in accordance to the question being tackled. It is not an experimental methodology as researchers do not conduct controlled experiments to try to measure the change. It is considered to be a qualitative research method as the results obtained from phenomenographic studies are often descriptive. Each individual participant contributes a portion of the data that make up a complete and collective experience when put together (Booth, 2001a).

Empirical phenomenographic research conducted by Marton and Säljö in the late 1970s on 'what students learn' gave rise to what is termed 'approaches to learning'. In their research, students were given an article to read after which the responses were analysed according to how the participants had approached the task. Their analysis revealed two qualitatively different approaches: the deep and surface approach (Marton & Säljö, 1997) and these are discussed in the next section.

## 2.1. Approaches to learning

The research conducted by Marton and Säljö (1976a) revealed the deep (meaningful) approach and surface (rote) approach. In the deep approach, students aim towards understanding. Students who employ a deep approach to learning look at a much broader picture by relating new ideas to the prior knowledge they held. This deep or meaningful approach involves dealing with learning a task by "attempting to form a relationship between newly-learned concepts and previously-learned concepts" (Ozkal, Tekkaya, Cakiroglu, & Sungur, 2009, p. 79). In the surface approach, students prefer to memorize as a method of learning. They are not able to integrate the new concepts with their previous knowledge. The main purpose of the surface approach is thus to replicate the course through routine procedures (Ozkal, et al., 2009). A third approach is also common and this is called the strategic approach (Atherton, 2010). The incentive in this approach is to achieve a predetermined performance level in the course using the assessment criteria as a guide (Atherton, 2010) . This is achieved by organized studying, effective time management, effort and concentration (Ozkal, et al., 2009). Entwistle and Peterson (2004) summarized the learning processes used in the deep and surface approaches and these have been reproduced as Table 1 overleaf.

| Deep Approach | Surface Approach | Strategic Approach |
|---|---|---|
| Relating ideas to previous knowledge and experience | Treating the course as unrelated bits of knowledge | Organizing studying thoughtfully |
| Looking for patterns and underlying experience | Routinely memorizing facts and carrying out procedures | Managing time and effort effectively |
| Checking evidence and relating it to conclusions | Focusing narrowly on the minimum syllabus requirements | Forcing oneself to concentrate on work |
| Examining logic and argument cautiously and critically | Seeing little value or meaning in the course or set tasks | Being alert to assessment requirements and criteria |
| Monitoring understanding as learning progress | Studying without reflecting on either purpose or strategy | Monitoring the effectiveness of ways of studying |
| Engaging with ideas and enjoying intellectual challenge | Feeling undue pressure and anxiety about work | Feeling responsibility to self or others for trying hard consistently |

**Table 1: Features of approaches to learning (Entwistle & Peterson, 2004)**



Other studies on students' approaches to learning have been conducted. Most of these studies were based on the research carried out by Marton and Säljö (Marton & Säljö, 1976a). Entwistle and Ramsden (1983) conducted a study in which students were asked to reflect on what they normally did in their studies. The focus was mostly on the way they tackle their tasks. The researchers used the Approach to Studying Inventory (ASI) and the results of their study revealed four learning orientations, namely the meaning, reproducing, strategic and non-academic orientations. The reproducing and meaning orientations correspond to the surface and deep approaches respectively. In the strategic orientation, the student uses either the deep or surface approach with the intention of maximizing marks. According to Marton and Säljö (1976b) most students are able to use both the surface and deep approaches. They adopt a certain approach depending on the requirements of that particular instance. Students who employ the non-academic orientation pay little attention to details. These students have no academic aspirations and often assemble irrelevant and disordered facts (N.J. Entwistle & Ramsden, 1983). Another study into how students approach learning was conducted

by Biggs (1987). This study produced very similar results to the study conducted by Marton and Säljö (1976a). In his study, Biggs (1987) used questionnaires and managed to identify three dimensions to learning. These were namely internalizing (deep approach), utilizing (surface approach) and achieving (strategic approach) dimensions (Biggs, 1987).

Van Rossum and Schenk (1984) conducted an investigation based on Marton and Säljö's study (1976a) to investigate the relationships between students' approaches to learning, conceptions and outcomes of learning. The results of their study suggest that a strong relationship exists between approaches to learning and conceptions of learning. This relationship is discussed in detailed in the section below.

## 2.2. Conceptions of learning

An interview study was conducted in the late 1970s, by Säljö where he asked a group of adults what learning meant. This study revealed five qualitatively different conceptions of learning. Research conducted by Marton and Säljö (1997) subsequently revealed a sixth conception. Learning was conceptualised by Marton and Säljö (1997) as:

i. an increase in knowledge
ii. memorising and reproducing
iii. the acquisition of facts, methods, etc, for subsequent utilisation
iv. understanding
v. seeing things differently
vi. developing or changing as a person

Biggs and Moore (1993) classify these learning conceptions as either quantitative or qualitative. The first three fall under quantitative learning and the last three are classified as qualitative. The quantitative conceptions are concerned with isolated items and lead to surface learning. The qualitative conceptions lead to a deep learning approach as the students understand the concepts. The findings of research carried out by Van Rossum and Schenk (1984) corresponded with Säljö's finding. The independent research by Van Rossum and Schenk (1984) obtained the first five conceptions which were grouped into two categories. The first three conceptions were grouped together as 'reproductive' and the remaining two were grouped as

'constructive' (Van Rossum & Schenk, 1984). This study by Van Rossum and Schenk (1984) also investigated the relationship between students' approach to learning, conceptions of learning and their learning outcome. The analysis revealed that there is a strong link between the conceptions and approaches to learning. They established that students who had reproductive learning conceptions often employed a surface approach to learning whilst those who had constructive learning conceptions utilized a deep approach to learning (Van Rossum & Schenk, 1984). In their study, van Rossum and Schenk (1984) used the Biggs' (1987) SOLO taxonomy to qualitatively categorize different learning outcomes. The students who employed a surface approach were said to have either a pre-structural or uni-structural level of learning outcome. However, some students were able to relate ideas together. They used the deep approach and were said to have reached the relational level. Ramsden (2003) acknowledges that learning outcomes, approaches to learning and learning conceptions are interconnected. To explain the relationship, he made use of the illustration below (Ramsden, 2003, p. 82)

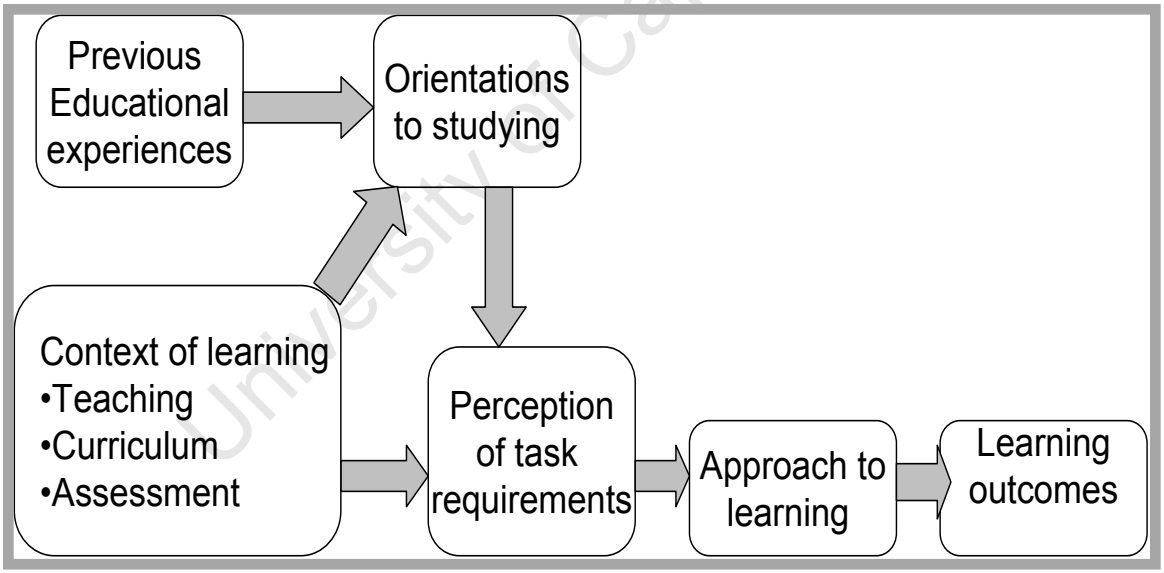


**Figure 2: Ramsden's model of student learning in context (Ramsden, 2003)**

From Ramsden's model, it is evident that there is a relationship between these. He states that:

> "Perceptions of assessment requirements, of workload, of the effectiveness of teaching and the commitment of teachers, and of the amount of control students might exert over their own learning, influence the deployment of different

approaches, which are very clearly adaptive responses to the educational environments defined by teachers and courses" (Ramsden, 2003, p. 82).

It is evident that the perceptions that students have of the work required influences the learning approaches that students adopt. For an abstract and complex concept such as sustainable development, active student-centred learning is required. This is because it encourages deep approaches to learning. Von Blottnitz (2006) argues that it is not possible to achieve mastery of complex subjects through passive-learning approaches. Further, he argues that students must adopt a deep approach to learning if they are to develop an effective understanding of a multidimensional concept such as sustainable development (von Blottnitz, 2006). An emerging and growing field of research, threshold concepts, offers a new way of conceptualising the way students learn. Within the threshold concept theory, is a link to approaches and the conceptions of learning as the last three conceptions that were discussed earlier as constructive concepts can be a way of identifying whether a student has grasped a threshold concept. The threshold concept theory will be explored in more detail in section 2.3. However, it is important to point out that students who employ a deep approach to learning and develop constructive learning conceptions are more likely to grasp threshold concepts when they exist within the curricula.



## 2.3. Threshold concepts

The notion of threshold concepts originated from an UK national research project, the Enhancing Teaching and Learning Environments (ETL) in Undergraduate Courses project. This project aimed at identifying the factors that lead to high quality learning environments within five disciplinary study areas. The research conducted revealed that within each discipline there are some ideas that are fundamental to students 'getting it'. Meyer and Land (2003) state that these ideas can be considered as 'conceptual gateways' or 'portals'.

> "A threshold concept can be considered as akin to a portal, opening up a new and previously inaccessible way of thinking about something. It represents a transformed way of understanding, or interpreting, or viewing something without which the learner cannot progress" (Meyer & Land, 2003 p. 1).

These conceptual gateways are essential as they help a learner to progress further into a deeper level of knowledge. The process of grasping a threshold concept "opens up a previously inaccessible and sometimes a troublesome way of thinking about something" (Meyer & Land, 2005, p. 373). However, when the process proves troublesome, it often leaves learners stuck and unable to move forward. Threshold concepts can be defined as "concepts that bind a subject together and are fundamental to ways of thinking and practising within a discipline" (Land, Cousin, Meyer, & Davies, 2005). This means that threshold concepts are likely to be the "turning points in a gradual shift from a novice mindset to an expert mindset and often leads to the notion of thinking like a practitioner" (Land, et al., 2005).

### 2.3.1. Characteristics of a threshold concept

Meyer and Land (2003) describe threshold concepts as 'core concepts', where a core concept is considered to be "a conceptual building block that progresses understanding of the subject" (p. 4). They further state that "threshold concepts are likely to be transformative, integrative, bounded, probably irreversible and are potentially troublesome" (Meyer & Land, 2003, p. 5). However, it is imperative to point out that threshold concepts will not necessarily display all these five qualities.

Threshold concepts are *transformative*, in that once acquired they may shift the way an individual views a certain subject or the world. The shift in perception may lead to a change of personal identity and is often characterized by a shift in feelings, values and attitude (Meyer & Land, 2003). According to Cousin (2009), the grasping of a threshold concept involves a conceptual shift and an ontological shift. "We are what we know. New understandings are assimilated into our biography, becoming part of who we are, how we see and how we feel" (Cousin, 2009, p. 202). It is therefore evident that the understanding of a threshold concept "involves a reposition of the self in relation to the subject" (Meyer & Land, 2005, p. 374). This identity shift is evident in a learner who, whilst struggling with certain concepts, is unable to identify himself as a practitioner. However, once the concept is understood, they begin to see themselves as experts.

Secondly, threshold concepts are probably *irreversible* as they are difficult to unlearn. Once an individual begins to see the world in terms of a threshold concept, it will be

unlikely that they return to seeing it in a similar way (Meyer & Land, 2003). Meyer and Land (2003) argue that this irreversibility can make it difficult for expert practitioners who have passed through a threshold to identify with the problems faced by those who are struggling to understand and to cross the threshold. Whilst a threshold concept is not likely to be unlearnt or forgotten, an individual's conception of it can still be modified or rejected (Cousin, 2009). However, this occurs from an internalised understanding of the concept (Cousin, 2009).

A threshold concept is often *integrative*. If a student has understood a threshold concept, they are more likely to assimilate different aspects of the subject (Land et al., 2005). This is described as the "capacity of a concept to expose the previously hidden interrelatedness of something" (Davies, 2003, p. 5) in that students are able to pull together bits and pieces of theoretical material and integrate them into a whole concept.

Meyer & Land (2003) also state that threshold concepts are *bounded*. Threshold concepts "help define the boundaries of a subject area as they indicate the limits of a conceptual area or the discipline itself" (Eckerdal et al., 2006).

Lastly, there is a possibility that when threshold concepts exist within curricula, they may be *troublesome* for students. This is because threshold concepts are likely to involve forms of troublesome knowledge (Cousin, 2009). According to Perkins (1999), troublesome knowledge is defined as "that which appears counterintuitive, alien (emanating from another culture or discourse), or incoherent (discrete aspects are unproblematic but there is no organising principle)" (Meyer & Land, 2003, p. 5-6).

The threshold characteristics are all closely related and interwoven. Davies and Mangan (2007) state that "a concept that integrates prior understanding is transformative as it changes a learner's perception of their existing understanding and thus is more likely to be irreversible, because it holds together a student's thinking about different phenomena" (p. 712).

### 2.3.2. Troublesome knowledge

Troublesome knowledge goes further than knowledge that is difficult to understand (Rountree & Rountree, 2009). Perkins (1999) argues that it is troublesome because it conflicts with one's current understanding or perspective. The transformative nature of a threshold concept makes it troublesome as it "involves letting go of previous comfortable positions and encountering less familiar and sometimes disturbing new territory" (Land, et al., 2005). Threshold concepts are often problematic as they demand an integration of ideas and this requires the student to accept a transformation of their own understanding. This transformation can entail a shift in identity and Land et al (2005) argue that this often results in students being stuck in an 'in-between' state in which they move back and forth between less sophisticated understandings and a more in-depth appreciation of a concept. This in-between state is called a state of liminality, and will be discussed in greater detail in the next section.

Scheja and Pettersson (2010) point out that "the procedure through which an individual obtains knowledge about a particular phenomenon may be taken so much for granted that it is reduced to a ritualized routine" (p. 223). Ritual knowledge has "a routine and rather meaningless character and it feels like part of a social or an individual ritual: how we answer when asked such-and-such, the routine that we execute to get a particular result" (Perkins, 1999, p. 9). Names and dates are classified by Perkins (1999) as ritual knowledge. Another example of ritual knowledge is following procedures in arithmetic. Baillie, Goodhew and Skyrabina (2006) argue that sometimes teachers create a naive version of the concept whilst attempting to make a concept seem more understandable. This leads to a form of ritualized learning because when students show no signs of understanding, they are simply asked to do more similar problems (Baillie, et al., 2006).

Knowledge may also be inert or foreign. Inert knowledge is rarely used and includes words that are understood but not actively used (Meyer & Land, 2003). Knowledge may also be considered inert in that while students may have a conceptual understanding of certain concepts, they fail to see how their understanding is related to real life (Scheja & Pettersson, 2010). Davies and Mangan (2007) argue that "academic

ideas which are retained as isolated pieces remain inert in the student's mind resulting in the surface approaches to learning" (p. 714) discussed above.

Foreign or alien knowledge emanates from perspectives that conflict with our own (Meyer & Land, 2003). Conceptually difficult knowledge is often troublesome (Perkins, 1999). Baillie et al (2006) state that students often mix scientific views with their own misconceptions during their attempts to learn difficult concepts. Sometimes the troublesome nature of knowledge arises from it being tacit. Tacit knowledge, according to Meyer and Land (2003), emanates from either the complexity of the knowledge or its seemingly inconsistent nature.

### 2.3.3. Liminal space

In their investigating of how students understand threshold concepts in various subject areas, Meyer and Land (2003) introduced the idea of liminality. Liminality originates from the Latin word 'limen' which means a threshold (Baillie, et al., 2006) and refers to a "suspended state in which understanding approximates to a kind of mimicry or lack of authenticity" (Meyer & Land, 2003, p. 13). This notion of liminality suggests that threshold concepts are hardly ever mastered in a light bulb or single 'aha' moment but rather over a period of time. This period of transition is commonly referred to as a state of liminality. Different individuals navigate the space in different ways with varying degrees of success. Meyer and Land (2008) suggest that variation may occur in three different stages of liminality i.e. pre-liminal, liminal and post-liminal. The pre-liminal state involves the variation in how the learner sees the concept come into view. It is about how the concept is initially perceived or apprehended. The liminal variation involves how the liminal space itself is negotiated and made sense of. Learners will either pass through the threshold or not. In the post-liminal variation, learners are able to make informed observation and enter into a new conceptual space. Kabo and Baillie (2009) captured the different ways in which students navigate the liminal state and the visual can be seen below.

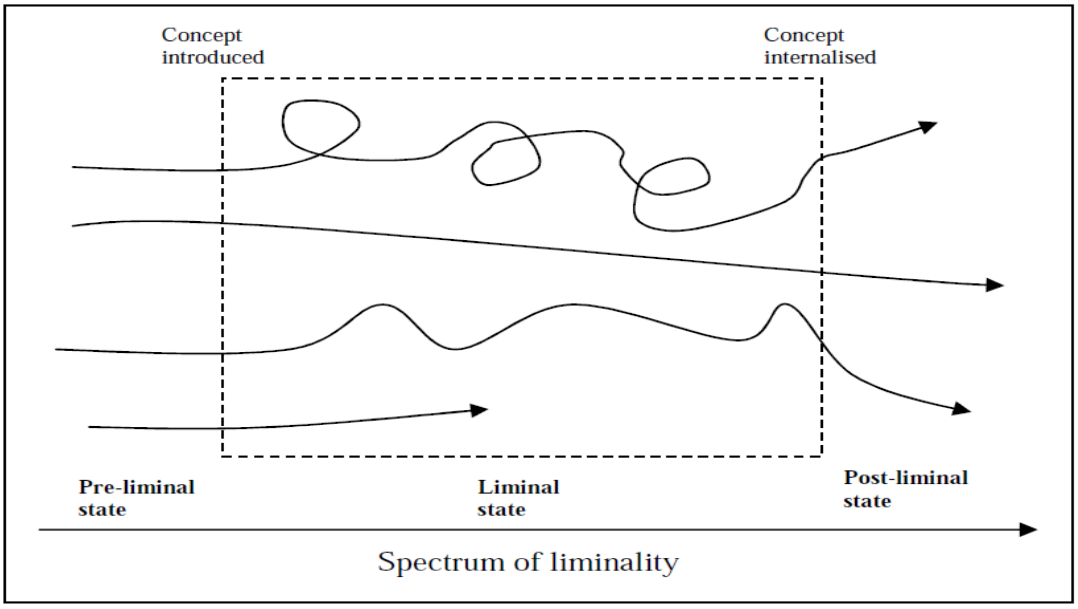


**Figure 3: How different students may navigate the liminal space (Kabo & Baillie, 2009)**

As evident in the figure, some learners might get stuck and be unable to move forward, whilst others might oscillate back and forth between different states of knowing. Baillie (2006) suggests that this transition is often unsettling, problematic, humbling and involves a sense of loss. Rountree and Rountree (2009) characterise students who are in the transition period to be undergoing a 'rite of passage' which is characterised by changes in states. Turner (1987) defines states as "relatively fixed or stable conditions" (Turner, 1987, p. 4) and proposes that the rite of passage describes the transition between one state to another. According to Turner (1987), the transition occurs in three stages: separation, margin or aggregation. The separation state involves the detachment of an individual from a known fixed and understood point. Once having separated, the individual is in an in-between state and in the last stage the individual is in a new stable state (Turner, 1987). The individual is considered to have acquired new knowledge, and therefore reached a new status and identity (Meyer & Land, 2005). Individuals are also said to have succeeded, where success is "defined as not understanding how a practitioner thinks but beginning to think like a practitioner" (Rountree & Rountree, 2009, p. 140).

Meyer and Land (2005) state that this transformation can be prolonged over considerable periods of time and often involves oscillation between states. Baillie et al. (2006) argue that students often mimic the language and behaviours associated with the new status without total understanding and meaning of what they are doing. They

may oscillate back and forth but once a student enters the liminal space, the student cannot return to the pre-liminal state. Meyer and Land (2005) have compared this to cultural initiations or to adolescence. They explain how adolescents often oscillate between childhood and adulthood and that this may be a protracted liminal state. In an attempt to navigate the liminal space, some students mimic the desired understanding or way of thinking. Whilst this mimicry can be step towards understanding, Cousin (2009) states that it can also be considered as a form of ritualised learning.

Threshold concepts are useful as they provide a link between approaches to learning and the learning outcomes (Davies, 2003). Lack of understanding results in surface learning but if students adopt a deep approach to learning they are able to understand the threshold concept (Davies, 2003). Threshold concepts offer a theoretical justification to the problems that students face while they are trying to develop an understanding of complex concepts (Davies, 2003). Because of this, threshold concepts maybe useful as a development tool for curriculum design (Davies, 2003).

## 2.4. Summary

Chapter 2 has reviewed the theoretical frameworks of learning that have informed this current study. The threshold concepts theory was chosen as a framework because it fits so well with sustainable development. Sustainable development is a vague concept with varying definitions and this might prove to be very troublesome for some students. If a student has fully understood sustainable development, a transformation should result. A deep understanding of the concept should lead to a shift in behaviour, a new and different way of looking at things and often a change as a person. This is consistent with the constructive learning conceptions that correspond to a deep approach of learning. An important educational implication of sustainable development being a threshold concept might be that it cannot be learnt by rote but rather through active methods.

# Chapter 3 Research methodology

The purpose of this chapter is to outline the research questions and the research design. The chapter also aims to provide a validation for the choice of research methods that have been used in this investigation. The research methods are described in terms of techniques and interview sample sizes.

## 3.1. Research questions

The work by Carew and Mitchell (2002, 2008) among others has demonstrated that there is an array of different dimensions of sustainable development. Further, they argue that the variations of what sustainable development is, can be expected as the concept is abstract and complex (Carew & Mitchell, 2008). Understanding the variation in the student's conception of sustainable development will potentially give some useful insights into how sustainable development can be taught so that students develop an optimal understanding. Booth (2001b) attests to this and states that analysing the variations that exist enables teachers to determine "where the students are in relation to the phenomenon being studied and thereby formulate goals, offer feedback and assess learning in line with shifting their understanding to desired goals" (Booth, 2001b, p. 12). For these reasons, I suggest that it is imperative that an investigation of the various dimensions of sustainable development be conducted and hence the first research question was formulated:

> **What are the different dimensions of sustainable development as understood by chemical engineering students?**

After understanding the different dimensions of sustainable development that are held by chemical engineering students, it is essential to consider the theoretical frameworks that exist. As stated already, sustainable development is a complex and abstract concept and such understanding results in seeing things differently. Because of this, the second research question was construed as threshold concepts offer a new and different manner of looking at how students learn and also brings about a transformed view of the subject matter:

> **Does the concept of sustainable development fit the definition of a threshold concept?**

From the discussions in Chapter 2, it is evident that approaches of learning can be linked to learning conceptions and outcomes. Carew (2004) argues that what students know, think and feel about the concept of sustainable development might provide insights into how students approach their learning about sustainable development and how motivated they are to learning. This is consistent with Booth (2001b) who argues that the approach that a student takes is a product of how the student interacts with the task, the way in which the concept is experienced as well as intrinsic interest in the subject matter. The perceived relevance and prior knowledge also influence the way students learn. Understanding the different ways that students learn might also provide a basis for promoting education of sustainable development. Because of this, it is pertinent that we investigate the different factors that influence the learning and understanding of sustainable development. It is on this basis that the third research question was conceived:

> **What have been students' experiences of learning about sustainable development in the undergraduate chemical engineering curriculum?**

## 3.2. Research design

To develop answers to the research questions outlined above, the research was carried out in two stages. The first phase made use of interviews and the second phase was an online survey. Interview questions were developed to examine the meaning, relevance and understanding of the concept sustainable development for chemical engineering postgraduate students. The researcher made use of purposive sampling which is sampling that occurs with some purpose in mind and contrasts with statistically representative sampling (Lincoln & Guba, 1985). This was because the researcher sought to discover maximum variation as opposed to generalizing the findings. Based on this, postgraduate students were chosen as they had been through the chemical engineering undergraduate program and it was assumed that amongst them might be those with sophisticated understandings of sustainable development. For the data analysis, the constant comparative method was used. This method provides a clear step by step outline of a process for analysing qualitative data. The first stage, also referred to as 'open coding' involves developing initial categories by grouping similar themes together. Once the data has been categorised, the data is scrutinised for commonalities and examined for properties that characterise each category (Strauss & Corbin, 1990).

This is done by asking questions; making comparisons and looking for similarities and differences between the comments. The next stage is termed 'axial coding' and this includes a further refinement of the categories (Strauss & Corbin, 1990). The categories are compared for overlap, and possible relationships between the categories are examined. The last stage 'selective coding' involves the validation of these relationships, and then further refining of the categories. The theory is then formulated and finalised (Strauss & Corbin, 1990).

### 3.2.1. Interviews

Interviews were selected as a mode of data collecting in the first phase as they are designed to bring out the knowledge a person has about a concept (White & Gunstone, 1992). The researcher opted for semi-structured face-to-face interviews as they permit for consistency of interpretation and focus across the sample of interviews and also allowed for interaction and further questioning of rationale (White & Gunstone, 1992). Since the main aim was to explore the different conceptions of sustainable development and to explore students' experiences of the concept, the interview was designed to allow the interviewee to discuss the topic comprehensively and also to provide an opportunity to elaborate thereon. To establish the trustworthiness of the results, the researcher kept a journal during the data collection phase. This also allowed for an independent observer to determine how the findings were obtained (Lincoln & Guba, 1985). A total of sixteen interviews were conducted. The interviews all took place in a pre-booked room in the New Chemical Engineering building. The interviews lasted between 30 and 50 minutes and were all audio-taped and then later transcribed. The summary of the interview transcripts can be viewed in Appendix II. Before each interview commenced, the researcher briefly explained the objectives of the research to the interviewee. Each interviewee was assured about the anonymity for reporting data in the thesis and it was also stressed that the interviewees could withdraw from the interviews at any stage. All interviews were conducted in a fairly relaxed manner so as get the interviewees talking. During the interviews, the researcher sought clarification for cryptic responses and often summarised the given responses so the respondent could elaborate, clarify or explain further. Two pilot interviews were carried out. These were conducted to establish the proper interview protocol and also to practise as the researcher had no prior knowledge of conducting interviews. By doing this, the

researcher was able to determine what interviews entail, the proper procedure to conduct interviews and how also to be able to relax. The pilot interviews also helped to establish which questions were relevant: after the pilot interviews a discussion was undertaken to determine how to frame some of the questions better.

The data analysis began during the course of the interviews. The researcher noted down some common themes and also some ideas that the researcher wanted to use as follow-up questions. During the transcription process, the researcher noted down recurring themes and formed preliminary categories and is consistent with the method of constant comparison discussed in section 3.2. This was done for better understanding and interpretation of the data. When this was complete, the researcher reviewed the transcripts again to ensure that all important data had been captured. Each transcript was then summarised and afterwards the researcher went through the transcripts again fitting the given data into the categories formed. During this process, more categories were formed and some categories grouped together.

### 3.2.2. Survey of 4th year students

After the interviews had been completed, the researcher then designed a survey to establish if the trends obtained would be similar with undergraduate students. The researcher opted for a survey as these are less time-consuming and offer a relatively simple and systematic way of collecting information (Robson, 2002). This was mainly because the schedule for the final years did not allow for the researcher to conduct in-depth interviews. The survey also allowed for anonymity thereby encouraging the respondent to be more open and frank about their responses. An online survey was constructed on SurveyMonkey™. The development of the survey consisted first of designing the appropriate test questions. The survey was divided into four parts and is included in Appendix III. The first part was basic information about the student and also included questions taken out from the survey by Azapagic et al. (2005). This was aimed at establishing the students' level of knowledge and understanding of environmental issues and the concept of sustainable development. The second section was aimed at establishing the conceptions of sustainable development held by students whilst the third section tried to ascertain if the concept of sustainable development could be characterised as a threshold concept. The last section aimed at determining the importance, relevance and response to the sustainable development challenge. The

initial draft survey was then tested informally to see if there were problems with it. After the pre-testing, the survey questions were revised before publishing the survey online. Students were asked to talk part in the survey and an email was sent out to all final year students with a link to the survey. The researcher hoped all the final year students would take part, however due to the students' hectic schedules and time constraints only 26 out of 78 students responded. The students were reminded to complete the survey through emails and announcements in the class. After the data collection, the responses obtained were collected and analysed.

## 3.3. Ethical conformance

To ensure that proposed research meets the highest ethical standard, the Engineering and Built Environment (EBE) faculty requires that research that proposes to use human participants for data collection undergo an ethics review. As such, the researcher submitted an ethics approval application form to the EBE Ethics in Research Committee (EiRC) before the data collection commenced. Approval was granted by the EiRC and the form can be viewed in appendix IV.

In an attempt to ensure ethical practices, the present study used informed consent. All participants were assured of their anonymity in this research project and that no direct reference would be made. The interviews were recorded after consent had been granted. Pseudonyms were used and all research participants were informed that this would be done. This was done to ensure the privacy of the research participants as most of them shared sensitive information about their teaching and learning experiences. As some of the information obtained in the research may reveal the identity of a participant, the researcher has summarised the interviews as opposed to having interview transcripts in the appendix.

## 3.4. Summary

In this chapter, the methodology informing the study has been discussed. Substantial data was derived from sixteen interviews conducted as well as the survey completed by 26 respondents. The process by which data were gathered and analysed has also been

described. This chapter provides a background against which the research results in the next chapter can be interpreted.

# Chapter 4 Interview findings

This chapter presents and evaluates the data obtained from the interviews with postgraduate students who had completed their chemical engineering degree at the University of Cape Town. The purpose of this chapter is to establish what students understand about sustainable development and to also establish whether sustainable development can be characterised as a threshold concept. In this section, results will also be presented on students' experiences of learning about sustainable development within the undergraduate curriculum.

## 4.1. Dimensions of sustainable development

The analysis revealed different meanings of sustainable development held by respondents. The many dimensions of the concept of sustainable development were expected because there is no general consensus in all the literature available on the subject as to what sustainable development is. From the analysis of student responses, different dimensions of sustainable development were identified and similar responses obtained were classified together. The breakdown is shown in the table overleaf and is ordered according to students who held the most dimensions to the least.

| Student | Sustainable development as responsibility | Sustainable development as lifestyle | Sustainable development as systems view | Sustainable development as appropriate design |
|---|---|---|---|---|
| **Thando** | x | x | x | x |
| **Allan** | x | x | x | |
| **Henry** | x | x | x | |
| **Lionel** | x | x | | x |
| **Harry** | x | x | | x |
| **Sizwe** | x | x | | x |
| **Kagiso** | x | x | | x |
| **Constance** | x | x | | |
| **Janet** | x | x | | |
| **George** | | | x | x |
| **Portia** | x | | | x |
| **Lethukuthula** | x | | x | |
| **Tatenda** | | | x | x |
| **Pride** | x | | | |
| **Grace** | | | x | |
| **Patience** | | | x | |
| **Total** | **12** | **8** | **9** | **8** |

**Table 2: Breakdown of students' responses**

As shown in Table 2, only one student described sustainable development using all four dimensions, six students expressed three dimensions; six students held two dimensions and three had only one dimension. The obtained dimensions are discussed in this section.

### 4.1.1. Sustainability as responsibility

A key theme that was apparent in twelve of the sixteen interviews was that of responsibility. Sustainable development from an engineering perspective is seen as being about taking responsibility for the impact of engineering on environment and society. The responses given suggested that the respondents are aware that they have a responsibility and a moral obligation to both the environment and society.

> *We need to realise that we all have a responsibility to the environment and that's why we have sustainable development because we've noticed that if we*

*don't do something about our habits today or the way that we use energy today [it] is definitely going to affect the future generations.*

*(Portia's interview)*

Within this category, the responses described sustainability in terms of management practices to ensure resources are not depleted. Some of the responses suggested that sustainable development is about respecting and observing system limits. Some of the respondents defined sustainable development in terms of the earth's carrying capacity and system limits.

This concept of sustainable development manifests itself as an obligation. Other responses obtained suggested that sustainability is about guarding the natural resources to ensure that they are not depleted beyond the earth's regenerative capacities. One respondent described the role chemical engineers should play as shown below:

*We have a responsibility to use our knowledge that we have for the development of our society and we need to fulfil that responsibility. We as engineers are therefore custodians of our own natural resources, because it's us who design the processes, it's us who should consider these things… when I think about process design or the role of a chemical engineer, I think of us more as custodians of the natural resources and we need to design and think about these things whenever we are implementing processes.*

*(Lionel's interview)*



### 4.1.2. Sustainability as a lifestyle

A total of eight respondents said sustainable development was a way of life. With this belief, most of them focused on changes in individual behaviour and thus made a more personal connection to sustainability. They talked mostly about their impacts and the things that they have done since grasping the concept of sustainable development to try and minimize the impact that they have on the environment. The focus here is more on personal actions, and sustainable development is seen as the consideration of human impact and behaviour on the environment.

*In my life it's about being aware of how I treat my waste, the amount of resources I consume or small things like using electricity or at least being aware of which of my personal things are environmentally friendly or not like*

*driving, when I drive I don't like flatten the gas. I drive in a way that I know I'm not wasting petrol you know or I try not to drive up and down; I try not to just jump into the car. Professionally I think it's influenced the way I see my future, like which jobs I want to take on.*

*(Constance's interview)*

*Well in terms of sustainability in terms of recycling definitely, our household has now changed to recycling plastics and so on but that has come as a function of [the] municipality that have sort of pushed that a little bit so we [are] definitely more conscious in terms of recycling our goods. In terms of organic waste we pretty much throw that into the garden, I think it's really wasted. Other than that I suppose in a way the new electricity prices as well force us to be more careful with our energy usage of the house and also the high petrol prices make us literally consider where you travel and who you visit. So I suppose sustainability has been implemented not only in [the] form of recycling goods but then also in terms of other things that we minimise.*

*(Harry's interview)*

Most of the responses within this category focused on the things different individuals are doing in their lives to reduce the impacts to the environment. It includes recycling, energy conservation, water conservation and also transportation. Some of the respondents acknowledged that though knowing about sustainable development had a major impact, the water restrictions, power blackouts and tariff increases also played a major role in influencing their decisions, as exemplified by the above quote from Harry's interview.

### 4.1.3. Sustainability as a systems view

The responses obtained suggested that eight of the students view sustainable development from a holistic perspective. To these students, sustainable development implies taking into consideration economic, political, environmental and social issues during decision-making and also into engineering design. Unlike other categories, the respondents emphasise the need to address social issues as being central to the concept of sustainable development. The respondents state that sustainable development is

about systems thinking and ensuring the integration and equal consideration of the social, economic and environmental issues. This they argued would ensure they have a holistic understanding of the concept and not just the environmental issues. This is clear in the illustrations below

> *Sustainable development is a bridge between science, society and economics.*
>
> *(Grace's interview)*

> *I think sustainable development is really just about trying to find a region where you have harmonious relationship between your social, economic and environmental considerations in the way you go about business or the way you go about everyday life. It is about looking for economic growth but with due consideration for the environmental consequences and social consequences of whatever path that you take.*
>
> *(Allan's interview)*

### 4.1.4. Sustainability as appropriate design

For eight of the respondents, sustainable development is all about changing the development paradigm through innovative design and the use of efficient novel technologies so that processes generate little or no waste. According to these respondents sustainable development is about optimising processes so that the processes use the least amount of natural resources and therefore conserve natural resources.

> *Sustainable development has made me realise that there is so much we can do as engineers in terms of the processes which already exist, we can change these processes or tweak them in such a way that the waste we end up producing is not harmful to the environment.*
>
> *(Tatenda's interview)*

> *I think the development is about looking at ways and looking at new products and the existing products that we currently make and reducing the effects on climate, social spaces and improving them.*
>
> *(George's interview)*

## 4.2. Does the notion of 'sustainable development' fit the definition of a threshold concept?

This section of the findings seeks to analyse the data and ascertain if the concept of sustainable development fits the definition of a threshold concept. This was done by inspecting the interview results under the various characteristics of a threshold concept as given by Meyer and Land (2003). From the analysis conducted, it was evident that not all the respondents made statements which suggested that they had experienced all the characteristics of a threshold concept. Table 3 overleaf gives a breakdown of how many of the respondents experienced the characteristics; the respondents are listed in the same order as in Table 2 for ease of comparison.

| Student | Transformative | Irreversible | Integrative | Troublesome | Liminality |
|---|---|---|---|---|---|
| **Thando** | x | x | x | x | |
| **Allan** | x | x | x | | x |
| **Henry** | x | x | x | | |
| **Lionel** | x | x | x | | x |
| **Harry** | x | x | x | | x |
| **Sizwe** | x | x | | | |
| **Kagiso** | | x | | x | |
| **Constance** | x | | x | x | x |
| **Janet** | x | | x | x | |
| **George** | x | | x | x | |
| **Portia** | x | | x | x | |
| **Lethukuthula** | x | | x | x | |
| **Tatenda** | | | | x | |
| **Pride** | | | x | | x |
| **Patience** | | | | x | x |
| **Grace** | x | | x | x | |
| **Total** | **12** | **7** | **12** | **10** | **6** |

**Table 3: Distribution of student experiences**

### 4.2.1. Transformative

The data analysis suggested that grasping the concept of sustainable development is indeed a transformative process. According to Meyer and Land (2003), understanding a threshold concept has the ability to shift the way a person perceives a subject. A lot of evidence was obtained that suggested that most of the respondents had experienced a change in their views and perceptions of their lifestyle, professions and life in general; clear evidence of this could be found in 12 of the 16 interviews. This is illustrated in their everyday lifestyles and the choices the respondents make. Most of the respondents discussed how they are more frugal and are more aware of their consumption patterns. Because of this awareness, they have changed their consumption habits and are actively indulging in practices that minimize their impacts on the environment. Some of the respondents discussed how they are trying to decrease their carbon footprint by using public transport, walking or bicycling as opposed to driving everywhere. According to other respondents, grasping the concept of sustainable development has made them limit their excessiveness especially of material things. Another respondent discussed how the knowledge of sustainable development revealed the importance of 'living within your means' i.e. economically and the benefits of recycling and composting. The findings indicated that grasping the concept of sustainable development is indeed transformative as most of the respondents now have a new perspective on the environment and their impact thereon. The extract below is just an example of the transformative nature of the concept of sustainable development.

> *I just try to minimize my own carbon footprint, personally like I don't drive anywhere. I try to use public transport as much as possible and to campus I just walk and take the Jammie shuttle, don't live beyond your means economically and recycle wherever you can…*
>
> *(Lionel's interview)*

The data analysis also revealed that the perceptions of the respondents have changed with time. The respondent's view of the role that chemical engineers play has evolved from merely thinking chemical engineering is about getting the best process, to actually thinking and considering the responsibilities or the ethics behind any design. The response suggests changing as a person or a change in identity as the respondent now

sees himself in the role of a protector or custodian of the environment as opposed to destroying the environment.

> *I think that as a fresh graduate back in 2007, my idea of chemical engineering was that we design processes, we fix problems, we calculate flow, we do a lot of mathematics-based stuff and at the end we come up with a process that works which is tweaked to perform optimally and that is my understanding or what was my understanding of chemical process engineering. What I failed to get at that point was the fact that we are also social capital. We have a responsibility to use the knowledge that we have for the development (I won't say growth) of our society and we need to fulfil that responsibility. We as engineers are therefore custodians of our own natural resources, cause it's us who designs the processes, it's us who should consider these things so I think that as a fresh graduate as compared to now.*
>
> *(Lionel's interview)*

### 4.2.2. Irreversible

The responses obtained from seven of the respondents implied that the concept of sustainable development is indeed irreversible in that it is unimaginable for these students to go back and think about their lives in the same light. This is perhaps evident in the changes that they make in their everyday life. One respondent talked about how understanding the concept made her view the world in a new light. This resulted in her doing things differently and changing her behavioural patterns. She believes the changes she are permanent. Another respondent gives an account of how understanding sustainable development impacted on his ideas when designing processes:

> *Initially what we were then taught in design is that design a process, then do your environmental, health and safety afterwards; once you've actually designed it. But what I would do now is to think about environmental, safety and health at every point whilst you are designing the process.*
>
> *(Lionel's interview)*

Some of the respondents discussed that grasping the concept of sustainable development involved a change in their habits. This implies that it is an irreversible concept as habits are difficult to break. The extract from Kagiso's interview below

indicates that once understood, the concept is ingrained within an individual and is thus irreversible.

> *I think these changes though they came as a result of restrictions, they are more long-term because it has become like habits, before like I used to think about it but now I don't anymore, it's become like a habit that's in me and so habits are quite hard to break.*
>
> *(Kagiso's interview)*

When asked if the changes they had made were long-term and permanent, all the respondents answered in the affirmative. They said it was unimaginable that they would go back to their previous ways of doing things as evident in the extract below.

> *I don't think I can go back because this is something that's in me like now I can't leave my heater on when I'm not at home and it's only logical that I switch it off so I can't go back and say there is enough energy so let me leave my heater on.*
>
> *(Sizwe's interview)*

### 4.2.3. Integrative

The respondents' accounts suggested that full understanding of what sustainable development is, involved both theoretical and practical aspects. They acknowledge that achieving sustainable development can only be realised if the three pillars (i.e. environment, social and economic) are intertwined. Because of their understanding of the concept, they are now able to address conceptual topics that they would not have had previously considered. The concept is integrative as it ties in with their understanding of other aspects. It also relates to the fundamental principles that they have learnt in different courses.

> *Essentially if you look at the plant design, sustainable development automatically comes in the form of optimising your system because by optimising your system you are reducing your energy, you are reducing your input and you are trying to reduce everything so you get your set target that you want to get out by minimising all your inputs. So sustainability also goes hand in hand I suppose with costs and optimisation so I suppose but not explicitly but implicitly it would be included in your mass balances, energy balance and so on.*
>
> *(Harry's interview)*

Some of the respondents discussed how the concept of sustainable development made them aware of the interrelatedness of systems. They state how sustainable development relates to various concepts and that these concepts are interlinked and dependent on each other implying thereby sustainable development is integrative. This integrative nature can also be linked to systems thinking because the idea of systems thinking suggests that sustainable development is about integration and equal consideration of social, environmental, political, financial and moral issues. This is implicit in the choice of terms and how the respondents talked about how sustainable development relates to other material and the links between the different bits and pieces to make a whole picture. Generally, there was a strong correlation between the detection of a transformative and an integrative theme in those interviews. This is expected as Davies (2003) argues that a concept that is integrative is likely to be transformative and irreversible. Further, they state that it is unimaginable that a concept can possess one of these characteristics without the other (Davies, 2003).

### 4.2.4. Bounded

From the analysis, there were no data obtained that suggested that the concept of sustainable development is bounded. According to Meyer and Land (2006) this is not unexpected as threshold concepts are not necessarily bounded. The respondents also stated that the sustainable development is a concept that applies to them professionally and personally and sometimes there is no clear separation. This could be due to the fact the concept is multidisciplinary and thus no demarcations can easily be made. This is also clear from the students' responses that suggest that sustainable development is a complex concept that involves economic and social aspects in it.

### 4.2.5. Troublesome

There is some evidence that the concept of sustainable concept is troublesome in that it conflicts with what Meyer and Land (2003) term the individual's previous ideas and also the letting go of previous comfortable positions. Because absolute understanding of the concept of sustainable development involves changes in an individual's life, it might prove troublesome for some people. This troublesome nature of the concept of sustainable development is clear in the accounts given by some of the respondents. According to these respondents, sustainable development is troublesome because

whilst they have the relevant knowledge of sustainable development they are not able to implement it as this means a complete overhaul in lifestyles and choices. Some respondents attributed the troublesomeness of the concept to the fact that they are not able to relate their conceptual understanding of sustainable development to real life. One respondent stated that the troublesomeness of the concept arose from the fact that whilst she is aware of the changes required in her life, she is not in a position to implement them. In her account, she gives examples of things she would like to implement were it possible.

> *I definitely think that when I'm fully in charge of my life, I will actually implement all those things. I will put light efficient bulbs, solar water heater; have a digester at home, gas cooker…*
>
> *(Grace's interview)*

Other respondents stated that the concept of sustainable development is troublesome because it conflicts with their personal values and future aspirations. For example one respondent states that whilst they recognize that big cars are not environmentally friendly and emit greenhouse gases, they still want to drive these cars.

> *I will be honest, choosing between a Land Rover Discovery versus like a Mazda or something like a bicycle, I'll go for the big car because I'm a man and the status thing but on the other hand I have to look at the environment so it's a tough one for me.*
>
> *(Kagiso's interview)*

The troublesome nature of sustainable development can also be attributed to the failure to translate the theoretical knowledge to action. This could be because people are reluctant to change and are set in their ways. Although most of the participants expressed concern about the sustainability issue, they acknowledged that sometimes they do not practice sustainability for various reasons.

> *You know it's there but you are not always able to implement it. So it has changed the fact that you know it's there and you should be doing it but it's not always a priority… I don't really practise sustainability as I don't think there's infrastructure to do it, like the recycling bins I heard they just throw them in together so certainly even though the ideas of recycling is there, there's nothing really to do it and why should I make the effort to throw it the designated bin when they are not even using it properly.*
>
> *(George's interview)*

### 4.2.6. Navigating the liminal space

Accounts of having experienced a liminal state were evident in six of the interviews. The liminal space is experienced differently by each individual and students exhibit different emotions and positions from pre-liminal state to the liminal state and finally to the post-liminal state. The interviews revealed that some of the individuals had gone through a space of uncertainty before fully comprehending the concept of sustainable development. The study also revealed that some students have difficulty changing their mindsets and adopting alternative views on development implying that they could be stuck in the liminal space (esp. Patience, in whose interview only the troublesomeness and the liminality were evident). Yet for some of the respondents, it could be said that they are in the transition period as they move back and forth in the liminal space from no understanding to fragmented understanding to internalizing the threshold concept. Because the liminal space is considered to be the time when the student is trying to attain a concept but has not yet succeeded, it is often characterized by partial understanding of the concept. This phase of partial understanding is evident in students with no or little understanding of sustainable development and indicates that some parts of the threshold have not come into a clear picture for them. These students are able to recite the definition of sustainable development, however they demonstrate no or little understanding of the concept, and they either do not know what sustainable development is or they provided a vague response. Six of the respondents acknowledged that they had a partial understanding of what sustainable development was when they first encountered it, as illustrated in the quotes below:

> *Well as I said, when I first encountered it, I think anyone who hears the term kind of has a feeling of what it is and what it involves. So you think SD and you think well that's what it involves. It's an easy concept to feel and to know but it's a difficult concept to define.*
>
> *(Thando's interview)*

However, in retrospect the respondents showed an appreciation that full understanding includes both the theoretical and the practical aspects and that sustainable development is not possible unless all the environmental, social and economic themes are intertwined. Some of the responses obtained suggested fragmented understanding. Here the students have begun to grasp the severity of the situation but do not yet have a

complete viewpoint. Whilst students in this phase demonstrate knowledge of more relevant facts, they are unable to relate the facts to each other and sometimes students feel that certain aspects of sustainable development are more serious than others.

> *Like I mentioned before it's like you kind of know that 'oh it would be nice to separate plastics from food waste for example and yet today I still don't do it. I put rubbish in one bin and I couldn't care less where it's going so it can't be 100% and it means I'm not living a fully sustainable life. But I know that for example if I was working for a company and I was involved in design because I think also it's a mindset like if I get back to the issue of global warming that is more serious to me than making a few landfills because you don't at this stage really see the effects, you don't feel the effects. I know this rubbish is going to landfills and cause pollution and methane production which also has an effect on the environment and yet because global warming is a bigger issue today, I find myself considering that to be more important than just a landfill you know so I think it's a mindset, a very bad one.*
>
> *(Portia's interview)*

At least twelve of the students stated that they were able to relate the various relevant facts to create a bigger picture. At this stage, the students knew what needed to be done. However they did not actually implement their knowledge for the different reasons given. Students mentioned that while they had a theoretical understanding they were unable to translate that understanding to practice and actual implementation. However, of these twelve only five students had came to the realization that having factual and theoretical knowledge of sustainable development was not sufficient and therefore these students are said to have gone beyond 'talking the talk' to 'walking the talk'. They practise what they preach and have internalized the concept such that it is ingrained within them. These students are able to apply their knowledge of the concept to solve problems. Some might say they have crossed the threshold and they are using the theoretical knowledge they have gained and actually making the necessary changes. The students have realized that being responsible is not enough but rather sustainable development requires each individual to reinterpret the call of duty and that personal action is a prerequisite for the change needed.

All of the subjects discussed the lengthy process of learning sustainable development. Some students took time learning the theoretical aspects and this could be due to the many varying meanings of what sustainable development is, making it difficult for students to comprehend. What was of interest was that most of the respondents realised the complexity of sustainable development and therefore suggested that learning the concept should be an ongoing process. One student only managed to actually use his own words when explaining sustainable development three years after first encountering it as a concept. This implies that maybe the respondent was actually struggling with it without even being aware. However, the respondent is now more confident than when he first encountered it, meaning that the learning process probably made him question himself.

> *Well to be honest, I think that when I first heard the term (in 2006) you kind of have a feeling for what it is but it's all this fuzzy idea in your head and you kind of put words to it. I was only able to put words to it last year (2009) as to what I understood by it and actually read some literature.*
>
> *(Lionel's interview)*

Meyer and Land (2005) refer to the liminal space as "problematic, troubling, and frequently involving the humbling of the participant" (p. 376). Because of this, the interviews were analysed from this perspective to determine if there was any evidence of emotional reactions. The analysis also showed that there was no lack of emotional reactions while trying to grasp the concept of sustainable development. Most of the respondents exhibit strong feelings which range from boredom, frustration, fear, hate and euphoria. This was expected as Meyer and Land infer that liminal spaces are unsettling, problematic and humbling. Also of interest was the fact that most of the respondents expressed worry about the future generations and the kind of lifestyle their children would lead. The respondents stated that they wanted to leave behind a good legacy and this has prompted behavioural changes. Other respondents stated that they were frustrated because they felt that their individual efforts in promoting sustainable development were useless. These students felt that sustainable development can only be achieved though teamwork and so they get upset when people around them indulge in unsustainable practices. At the same time other respondents felt that the realisation of the sustainable development goals was both unrealistic and naïve.

## 4.3. Students' views on learning about sustainable development

The interviews revealed that all respondents felt that there was insufficient exposure to the concept during their undergraduate studies. Whilst all the respondents claimed to have obtained their knowledge of sustainable development through their undergraduate degree, they all state that they had to do more reading on their own for a better understanding of the concept. They said that though the lectures gave an introduction to the concept, there was not enough engagement with the concept. In at least two of the interviews, the respondents felt that the concept was taught as an afterthought. This is illustrated in the extracts below:

> *I think it's about not looking at sustainability as a stand-alone thing but integrating it within the entire curriculum, curriculum development and teaching practice. Not as an afterthought; oh by the way there is environmental issues, there is social issues but right from the start of your learning, whatever it is you are learning, what are the consequences of what it is you are doing?*
>
> *(Allan's interview)*

> *So there's an introduction to the concept but I feel that there isn't enough engagement with it and I think it's mostly as an afterthought as opposed to being as a design objective almost… so I think whilst there is an introduction here… there could be more engagement and integration.*
>
> *(Grace's interview)*

> *It (sustainable development) needs to be at the core of your curriculum not an elective which you learn; it needs to be something that you refer back to as a starting point.*
>
> *(Lionel's interview)*

Students stated that sustainable development is a concept that should be promoted throughout the university and not just in engineering. This is because sustainable development is a multidisciplinary concept that can only be achieved if professionals from different fields work together. One of the respondents felt that sustainable development was a concept that was not taken seriously.

*A lot of people still think that sustainable development is just noise in the background and they are not to blame because it's the same attitude towards other groups within the department about the 'green guy'.*

*(Grace's interview)*

In at least five of the interviews, the respondents made a connection between sustainable development, education and engineering practice. For these respondents, sustainable development can only be possible if changes are made within engineering education. The general consensus amongst these respondents is the role that chemical engineers play in implementing sustainable development. The respondents stated that to achieve sustainable development, it is imperative that engineers use the concept of sustainable development as a starting point and framework to base their practices on. This is clearly articulated by Grace in the extract below:

*I think for me there is a need for a new type of engineer, one who understands those three platforms, environment, society and economics, because unless the project is financially viable nothing will happen, so whatever is being created as scientists or engineers we need to understand the impacts on society and how we can make it financially viable.*

*(Grace's interview)*

Ten of the respondents stated that institutions such as governments and universities play an important role towards promoting sustainability. This role of government and universities as influential players in promoting and implementing sustainable development is consistent throughout the case study. These respondents felt strongly that a lot can be achieved if both the government and universities worked together. According to the respondents, the government plays a major role as it sets policies and the universities enhance knowledge and establish role players through both mentoring, coaching and research opportunities. This is evident in the extracts below:

*I think if there's ever anyone that could play a role it is universities and governments. The governments, because nothing will ever be done unless there is a policy for it or there is a law for it. So once science confirms something - that's where the university plays a role because the university is supposed to be giving the knowledge out there.*

*(Grace's interview)*

*I think education institutions are definitely the most important player in addressing the issue 'cos I mean governments typically because whoever goes into government will come from an education background and depending on what they picked up from that background they will either try to implement or modify or whatever.*

*(Allan's interview)*

*So universities' responsibility is therefore to train people to think with this (sustainable development) in mind at all times.*

*(Lionel's interview)*

It is quite evident from the extracts that students thought that the government and educational institutions play an essential role in promoting sustainable development. While this was anticipated from the literature review, it was a recurring theme in most of the interviews.

# Chapter 5 Survey findings

The survey was targeted at the final year chemical engineering class enrolled at the University of Cape Town. The survey was conducted a week after the students had completed a sustainable development module in the Business, Society and Environment (CHE4048F) course. The main purpose of the survey was to determine if there are similar trends amongst undergraduate students with regard to the dimensions of sustainable development they have and if they view sustainable development as a threshold concept. The survey also aimed at assessing how students respond to the sustainable development challenge and if they are interested in learning about the concept. The response rate for the survey was 31%. Of the 26 students who responded to the survey, 36% and 64% were female and male respectively (relative to a class demographic of 39% vs. 61%). The low response rate might be attributable to a high project workload. It is likely that the troublesome nature of sustainable development might have led to the poor response rate.

## 5.1. Level of knowledge of sustainable development related topics among engineering students

In an effort to relate how much this group of students knew about sustainable development relative to what has been reported elsewhere, students were asked to rate their knowledge of sustainable development related topics. The questions used were taken from the worldwide survey conducted by Azapagic et al. (2005) which was discussed in section 1.4. The students were requested to rate their knowledge of the given topics from 1 to 4 which corresponded to 'not heard of' and 'know a lot' respectively. According to the analysis, some students stated that they 'have some knowledge' or 'know a lot' about acid rain, global warming, air and water pollution. Some of the students claimed that although they had heard of the some of the topics, they could not explain them (the numbers in the brackets refer to the number of respondents for each category). These topics included salinity (9), desertification (8), biodiversity (7), photochemical smog (5), ecosystems (4), deforestation (3), depletion of natural resources (2), ozone depletion (2), climate change (1) and solid waste(1). However, some students also stated that they had "not heard of" topics such as

photochemical smog (9), salinity (5), solid waste (1) and desertification (1). The exact breakdown of the students' responses is shown in Figure 4 below.

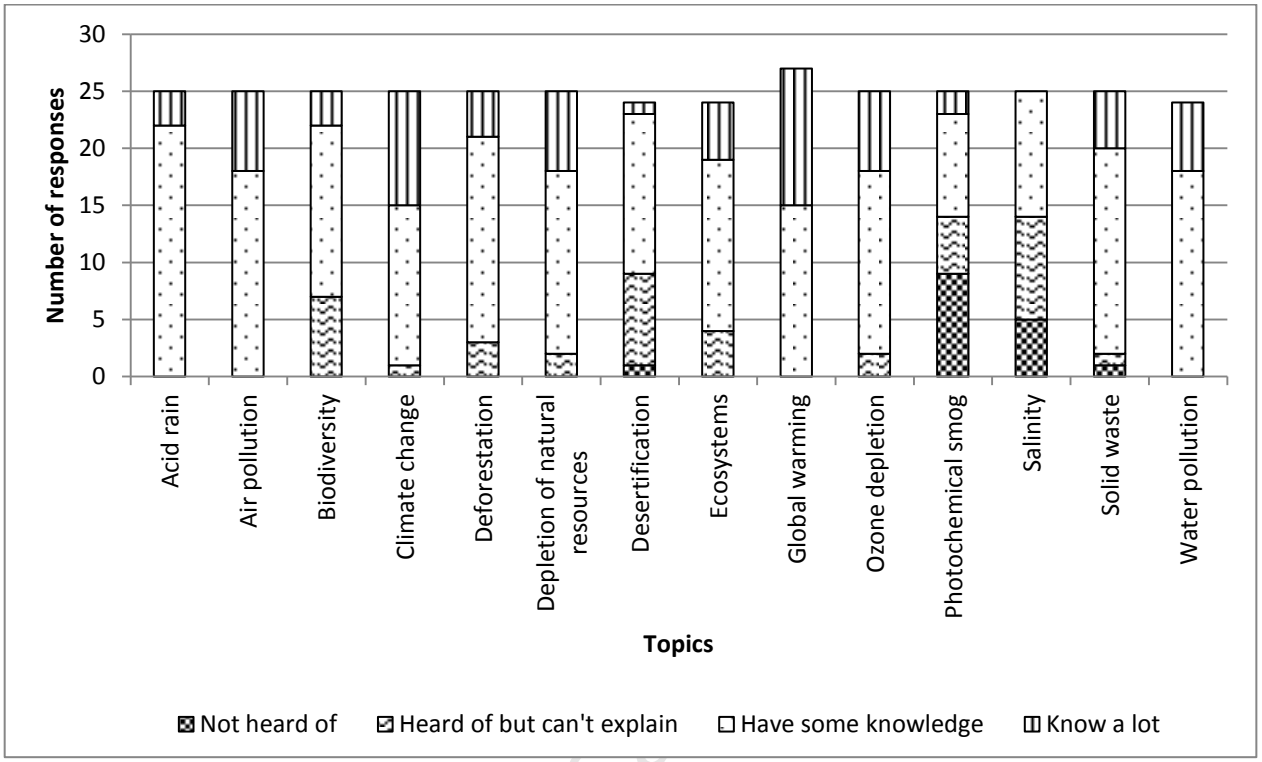


**Figure 4: Level of knowledge and understanding of environmental topics**[1]

Similar to the study by Azapagic et al. (2005), students were then asked about the importance of sustainable development. The table below gives a breakdown of student responses.

| Is working towards sustainable development important? | Response count (%) |
|---|---|
| Not important | 0 |
| Somewhat but it is not a top priority | 0 |
| Yes it is important but not a top priority | 31 |
| Yes, it is a top priority | 69 |
| I don't know | 0 |

**Table 4: Students' responses to the importance of sustainable development**

[1] One student only gave a response for one topic and some missed out other topics hence the inconsistent total

It is evident that all of the students responded in the affirmative and stated that sustainable development is an important concept. However, 31% of these respondents said that though sustainable development is important, it is not a top priority, compared to 69% who did view sustainable development as a top priority. This is of interest and is consistent with the study by Azapagic et al. (2005) in that the majority of the students surveyed thought that sustainable development was either 'important' or 'very important'.

## 5.2. Dimensions of sustainable development

To establish what students understand about sustainable development, they were given two questions. First, participants were asked to choose from a given list what they thought was the best definition of sustainable development. They were requested to rank their choices on a scale from 1 to 5 where 1 was the best definition. The rating averages for the responses are given in the table below.



| **Definition of sustainable development** | **Rating average** |
|---|---|
| Environmental protection & resource management | 1.9 |
| Intergenerational & intragenerational equality | 2.8 |
| Efficient use of resources through innovative technology | 2.9 |
| Provision of clean air, water and education | 3.0 |
| Environmental accounting & eco-efficiency | 3.1 |
| Poverty alleviation, provision of housing & basic service delivery | 3.4 |
| Fundamental changes in consumer behaviour and consumer patterns | 3.5 |
| Ethics, social justice & participation in decision making | 3.9 |

**Table 5: Definitions of sustainable development**

From Table 5 above, it is clear that environmental protection & resource management were considered as the best definition of sustainable development. Intergenerational & intragenerational equality and efficient resource use ranked 2nd and 3rd best respectively. It is also clear from examining the responses given by students that social issues are not considered to be of highest relevance to sustainable development. This is especially evident in that the majority of the students' ranked social issues such as

ethics, social justice, poverty eradication, provision of services, housing, education and clean air as less important. This is an expected result as traditionally engineers are more concerned with economic and ecological concerns than social issues. This could be because traditionally there has been very little learning time allocated to social and political issues.

The respondents were then asked to list three words that came to mind when they heard the term sustainable development. This was done to try and determine what the students associate most with sustainable development. The students' responses were analysed and it was possible to identify five different dimensions of the concept of sustainable development. Of these five dimensions, four were similar to the ones obtained from the interview analysis. A new dimension that arose from the survey was that of seeing sustainable development as tackling social issues. The different facets of sustainable development are discussed in detail below:

### 5.2.1. Sustainable development as responsibility

The responses classified in this category define sustainable development in terms of the environment and environmental protection. The respondents used terms that make reference to living harmoniously with nature or living in a balanced way that does not negatively impact on the environment. With this facet, the respondents used terms such as environmental protection, preservation, stewardship and conservation of natural resources. Other responses obtained in this category describe sustainable development as effective resource use and some of the expressions used described human management practices that would ensure that resources would still be available for future generations. From these terms, sustainable development involves recycling and looking for alternative resources. Also within this notion of sustainable development as responsibility are practices such as reforestation and biodiversity restoration.

### 5.2.2. Sustainable development as a lifestyle

Sustainable lifestyles and terms that make personal connection to sustainable development were classified here. The responses here suggest individual practices that are part of the respondents' lives like recycling, re-use, reducing consumption, conservation of water and energy. Here sustainable development entails considering

the impact of an individual's decisions on the environment and taking responsibility by adapting lifestyle.

### 5.2.3. Sustainable development as a systems view

Here the respondents used terms that suggest that sustainable development is an inter-disciplinary concept. The responses obtained include systems thinking, triple bottom line, interconnectedness. The choice of terms by the respondents implies that sustainable development is an interdisciplinary concept that should be tackled from a holistic perspective.

### 5.2.4. Sustainable development as appropriate design

Within this category, respondents use terms such as process optimization, eco-friendly, cleaner production, technological advancements and innovative design. Sustainable development is seen as tackling pollution and using green technological practices. Most of the respondents used expressions that suggest that sustainable development is concerned with waste minimisation through recycling. One response within this category suggests sustainable development as a process of change from traditional engineering to 'innovative inventions' that ensure longevity and future growth.

### 5.2.5. Sustainable development as addressing social issues

In this category, the respondents use terms that describe sustainable development as tackling social problems such as poverty, healthcare, education and unemployment. The emphasis is on improving society. One respondent stated that the millennium development goals (MDGs) are what come to mind in relation to sustainable development. This is expected as the students would have studied the MDGs in the CHE4048F course that had just been completed before the survey was administered.

## 5.3. Does the notion of sustainable development fit the idea of a threshold concept?

In the survey, the researcher tried to establish if the concept of sustainable development can be described as a threshold concept. This was done by asking the participants if they agreed or disagreed with the statements in the table overleaf:

| Characteristic | Statement |
|---|---|
| Transformative | My understanding of sustainable development has made me more frugal and aware of the impact I make on the environment |
| Integrative | Sustainable development relates to courses I have learnt and ties in with the fundamental principles of mass & energy balances and process design |
| Irreversible | Now that I understand what sustainable development is, I can't go back to viewing things in the same way |
| Troublesome | When I buy a car, the brand will be more important than eco-efficiency |
| Liminality | Even though I have been exposed to the concept of sustainable development in class, I still fail to see how they can be applied to chemical engineering |
| Liminality | Initially I struggled with the concept of sustainable development as it was a fuzzy idea but now I have a better understanding of what it entails |

**Table 6: Statements to explore the characteristics of threshold concepts**

The statements used were constructed based on the interview extracts. Two questions were given to explore the notion of limality as this was difficult to ascertain from the interviews and required more probing than with the other characteristics. The results from the survey are shown in the bar graph overleaf[2].



[2] SD in Figure 5 is an abbreviation for sustainable development

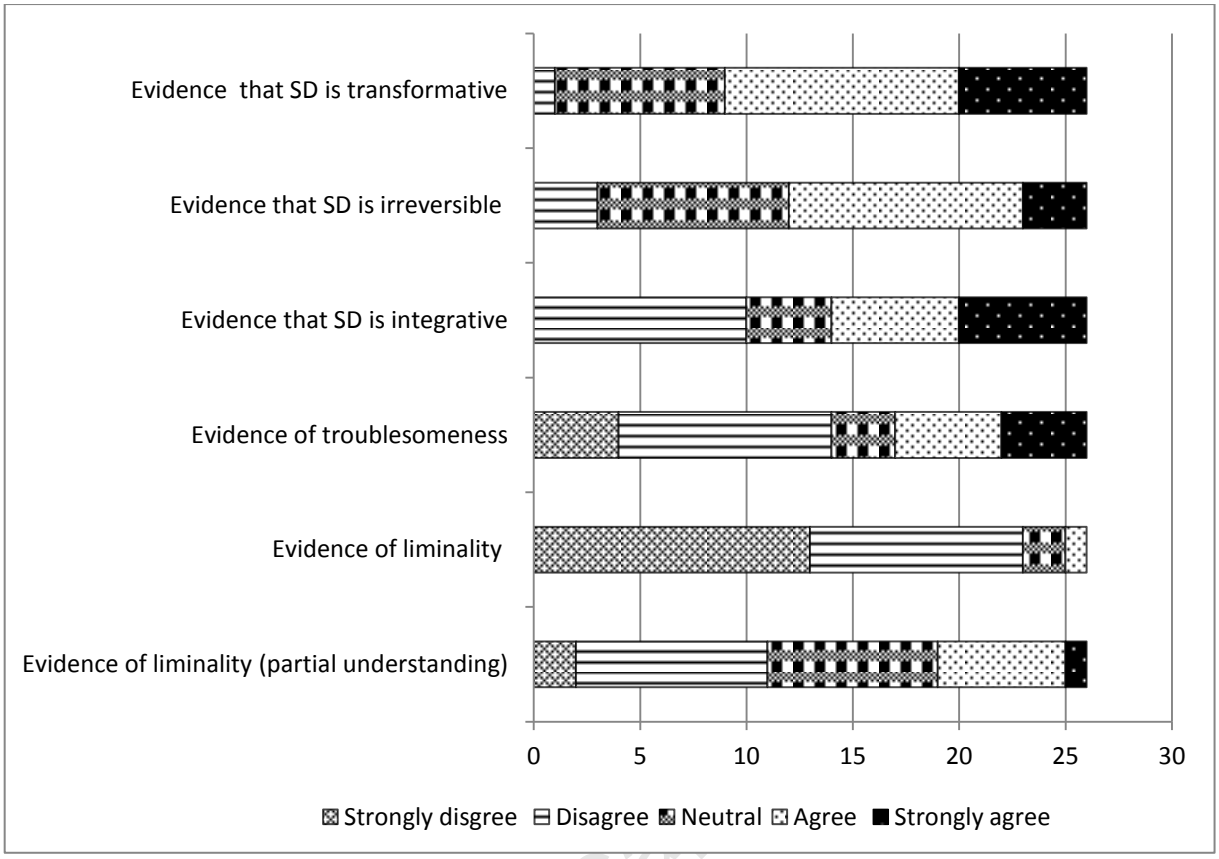


**Figure 5: Characteristics of threshold concepts experienced by students**

Clearly from Figure 5, it is apparent that the process of learning and understanding the concept of sustainable development has some characteristics of threshold concepts. These results will be discussed below:

### 5.3.1. Transformative

In an effort to determine the transformative nature of sustainable development, the researcher asked if the understanding of the concept led to students being aware of the impact they have and if it had led to changes in their consumption patterns. Of the responses obtained, more than half the students stated since grasping the concept of sustainable development, they are more conscious of the impact of their activities on the environment and have become more cognisant of resource use and consumption. The change to be more careful and aware implies the grasping of the concept of sustainable development is a transformative process.

### 5.3.2. Irreversible

To ascertain whether grasping the concept of sustainable development was irreversible, the researcher asked the students if their understanding had led to a permanent change. Of the respondents, 12% disagreed with the given statement and 35% were neutral. Of the students who agreed with this statement, a total of 12% strongly agreed while 42% agreed. This implies that for just over half of the respondents the grasping of sustainable development is irreversible and also involves a transformed view of seeing.

### 5.3.3. Integrative

To establish if the concept of sustainable development is integrative, students were asked if they agreed or disagreed that the concept of sustainable development related to courses that they had learnt and also if it tied in with the fundamental principles of chemical engineering like mass and energy balances and process design. 46% of the students responded in the affirmative and said that sustainable development tied in with the courses that they had learnt. This suggests that for these respondents, grasping of sustainable development is integrative. However 15% were neutral and 39% of the respondents failed to see the interrelatedness between sustainable development and fundamental principles they had learnt. This implies that these respondents fail to see how sustainable development is linked to their work and thus it might prove problematic for them to try and implement any sustainable practices into their engineering work or even personal life.

### 5.3.4. Bounded

In the survey, this characteristic was not tested for. This was because there was no data from the interviews to imply that the concept of sustainable development is bounded. Also because the concept involves different aspects from social, economic, political and environmental fields, it was hard to come up with statements that test for the evidence of a threshold concept being bounded.

### 5.3.5. Troublesome

For this characteristic, students were given the statement “when I buy a car, the brand will be more important than eco-efficiency”. The responses obtained for this statement varied considerably. A total of 9 students agreed with the statement and claimed that brand was more important than eco-efficiency. Four and ten students strongly

disagreed and just disagreed respectively and thus these 14 students claimed that eco-efficiency was more important and 10 students were neutral. For the students who stated that brand was more important than eco-efficiency, this either shows that the individuals do not have the relevant information about sustainable development, or they are still conflicted when it comes to making personal choices. This indicates how troublesome the concept is and also possibly attests to the liminality characteristics of a threshold concept. For the respondents who stated that eco-efficiency was more important than brand, it can be inferred that these students have grappled with the concept and now have an extended understanding.

### 5.3.6. Navigating the liminal space

To explore the idea of limality, the respondents were given two different statements. The first statement was to test for partial understanding. This was because the liminal space is often characterised by partial attainment of the concept. With this statement, there was little evidence of partial understanding as only three students acknowledged it. The respondents were asked if they agreed or disagreed with the statement below:

> *Initially I struggled with the concept of sustainable development as it was a fuzzy idea but now I have a better understanding of what it entails.*

When given the above statement, a total of 4% strongly agreed while 23% merely agreed. This means that 27% of the respondents state that they now have an improved understanding of sustainable development than when they first encountered the concept. However, 31% had a neutral response while 8% and 35% strongly disagreed and disagreed respectively with the statement. This means that either these respondents do not yet have a better idea of what sustainable development is and what it entails, or that they did not struggle with it. This could be because of the vagueness of the concept might prove difficult and could also imply the possibility of liminality. The participants were also asked to agree or disagree with the statement below and there was evidence of liminality from 7 of the 26 students.

> *Even though I have been exposed to the concept of sustainable development in class, I still fail to see how they can be applied to chemical engineering*

A total of 88% of the respondents disagreed with the statement implying that they are able to see how the concept of sustainable development can be applied to chemical engineering. If students are able to link sustainable development to engineering then it

means engineers can use the principles of sustainable development in engineering practice. While only a few students attested to having undergone the liminal space while grasping the concept of sustainable development, it is possible that the students who disagreed and / or were neutral were not aware that they were in the liminal space.

## 5.4. Students' experiences of learning about sustainable development

From the literature view, it is evident that interest and motivation often lead to a deeper understanding. The students were also asked which topics they would be interested in learning more about. The analysis revealed that students chose a diverse range of topics as evident in Table 7 below:

| Topic | Response count | Response rate (%) |
|---|---|---|
| Renewable energy technologies | 17 | 65 |
| Social responsibility | 15 | 58 |
| Sustainable design | 14 | 54 |
| Waste management | 11 | 42 |
| Environmental regulations | 10 | 39 |
| Ethics | 10 | 39 |
| Life cycle assessment | 3 | 12 |

**Table 7: Topics engineering students are interested in learning about**

A lot of the respondents indicated that they would be interested in learning more about renewable energy technologies, social responsibility and sustainable design. However, life cycle assessment and ethics were the least popular topics. This is not surprising as topics such as ethics are not considered 'hard' engineering topics. Another reason for this could be that students do not see an immediate relevance of these topics to their engineering practice.

Despite the low level of knowledge about certain sustainable development-related topics, all the respondents stated that they were responding to the challenge of sustainable development either by learning more about the concept, taking action personally and / or mobilizing others to act. Of interest was that none of the students

stated that there was nothing they could do but rather all respondents were tackling the issue in different ways. The responses are shown in the pie chart overleaf.

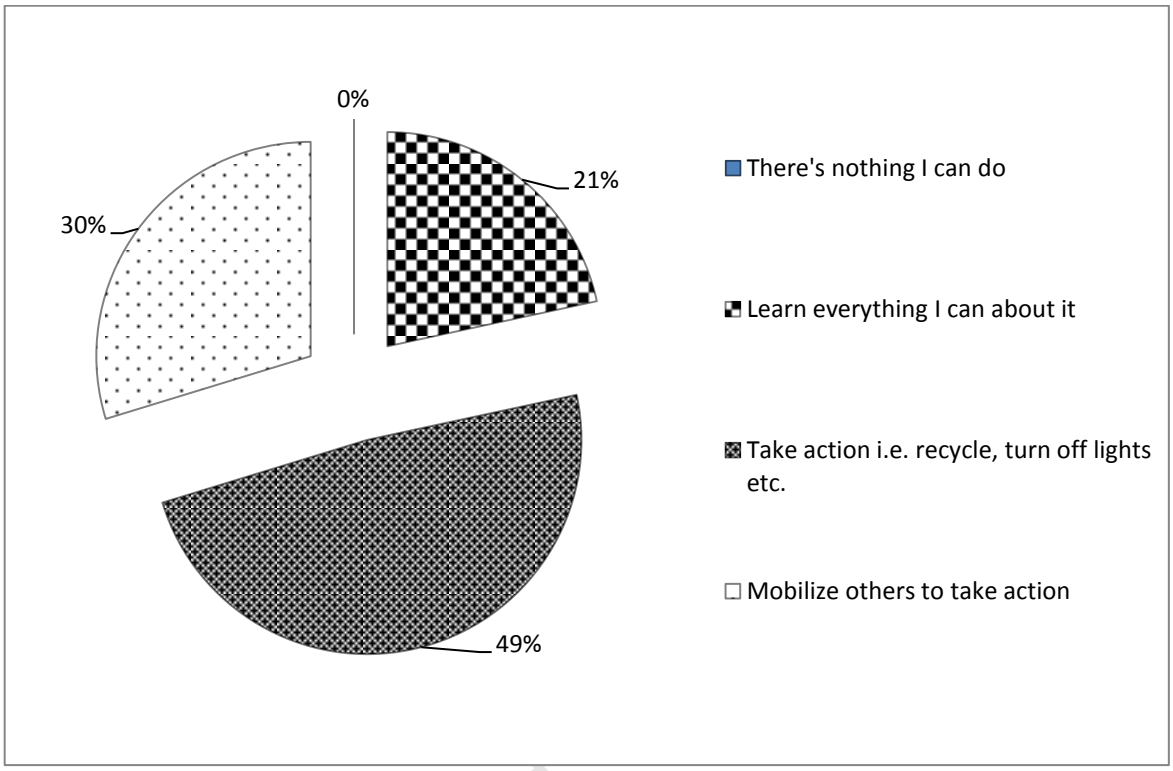


**Figure 6: How students relate to the sustainable development challenge**

# Chapter 6 Discussion and conclusion

## 6.1. Introduction

The previous two chapters have provided an analysis of students' conceptions, views of learning on sustainable development and also outlined the evidence that suggests that sustainable development is a threshold concept. The analysis was conducted firstly through interviews (see Chapter 4) and then elaborated on by the survey discussed in Chapter 5. The purpose of this chapter is to provide a general discussion and to suggest the implications of this study. In the first section of this chapter, a comparison with previous studies that have been conducted is provided. This is then followed by a discussion around students' dimensions of sustainable development as well as a discussion on characterising sustainable development as a threshold concept. The implications of the findings are given as well as concluding remarks and recommendations for future work.

## 6.2. What do students know about sustainable development?

As discussed in section 5.1 in the previous chapter, the level of knowledge on topics related to sustainable development amongst the undergraduate chemical engineering students closely matches the findings of the Azapagic et al. (2005) but is significantly higher than the Davis and Wanous (2007) study. The research conducted by Azapagic et al. (2005) and Davis and Wanous (2007) provides a useful international comparison for this finding. Azapagic et al. (2005) found that students were knowledgeable about high profile like global warming and acid rain. However, the level of knowledge on the other environmental issues was relatively low. Davis and Wanous (2007) carried out a similar study and revealed that the level of knowledge of engineering students was lower than that obtained in the investigation by Azapagic et al. (2005).

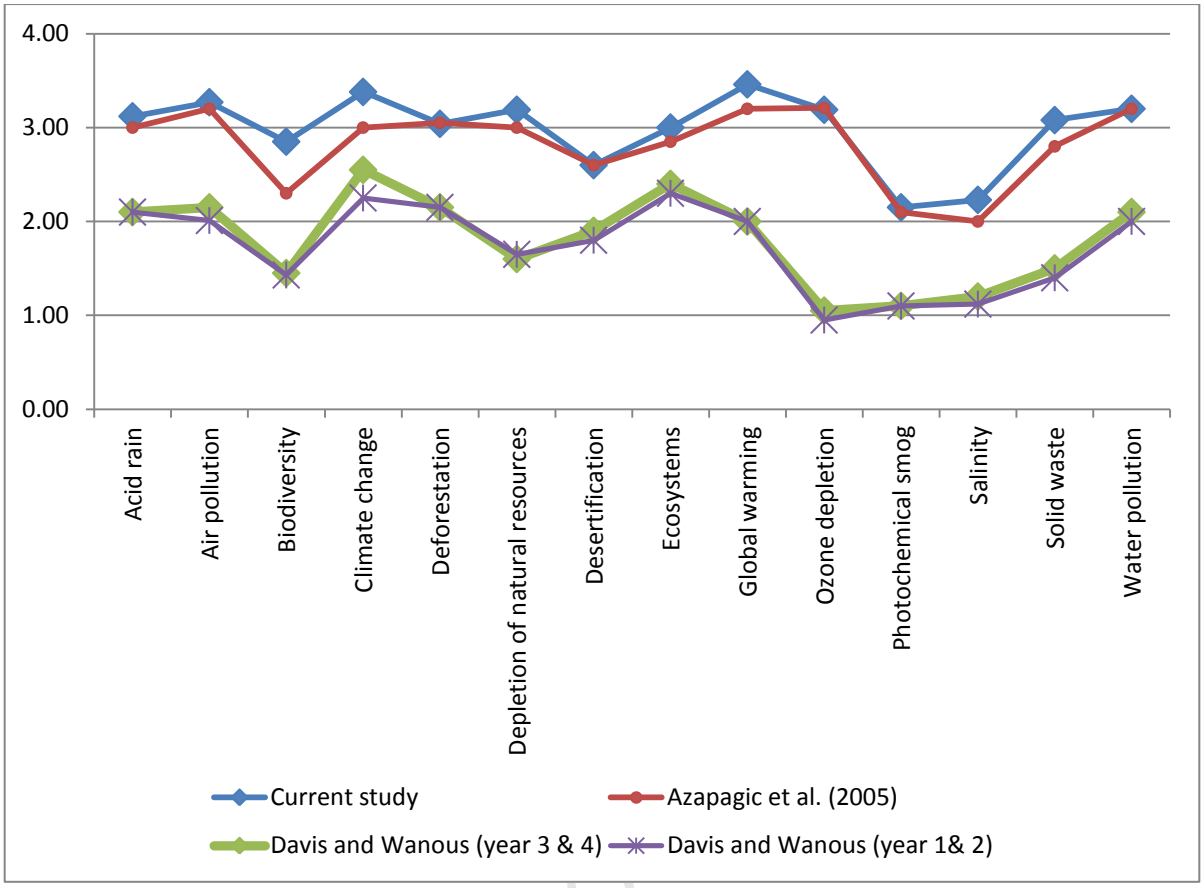


**Figure 7: Comparison on the understanding of environmental issues**

From the trends in Figure 7, it is clear that the results of the current study show a slightly higher level of knowledge of the environmental issues than previous studies. This could be because the participants of the current study had just completed a module of sustainable development which covered environmental issues. The survey results indicate increased knowledge for topics such as global warming, biodiversity, climate change, and air and water pollution. Of interest is that in all three studies conducted, students seem not to have a good knowledge about photochemical smog and salinity. There is a markedly increased level of knowledge about biodiversity as compared to the Azapagic et al. (2005) and Davis and Wanous (2007) studies. This could be due to the increased publicity of the concept as 2010 was the international year of biodiversity.

A commonality of the current study to the studies conducted by Azapagic et al. (2005), Carew (2004) and Davis and Wanous (2007) was that all respondents stated that they

were interested in learning more about sustainable development and felt that the concept was very relevant to their professional careers.

## 6.3. Dimensions of sustainable development

The findings of the study revealed five dimensions of the concept of sustainable development. Four of these emerged during the interviews and these are namely sustainable development as a responsibility, sustainable development as a lifestyle, sustainable development as a systems view and sustainable development as appropriate design. These four dimensions were confirmed in the survey study together with a fifth dimension, namely sustainable development as tackling social issues. The different dimensions of sustainable development as understood by students suggest that there is significant variation in the way that students perceive sustainable development.

From the data analysis, it was evident that the majority of students strongly associated sustainable development with the environment as opposed to social and economic aspects. This would suggest that sustainable development is seen generally by a majority in one dimension with the environment instead of a holistic interpretation. This result implies that engineering education needs to link environmental issues more strongly with social, political, cultural and economic aspects. If this is achieved, engineers can be in a position to understand the complexity and interconnectedness of sustainable development and thereby address the challenges.

The different dimensions of the concept of sustainable development pose a challenge to engineering education and raise the questions:

- What is the best way to infuse sustainable development into engineering curricula?
- How can these different facets of sustainable development be used as a framework for student learning?
- Can these multiple dimensions enrich the learning of sustainable development?

To answer these questions, extensive thought and research on the best way of successfully incorporating sustainable development into curricula is required. Another significant challenge that arises is how engineering curricula can be constructed so as to cater for students with less sophisticated understanding to build their competency

while simultaneously allowing the 'stronger' students to explore the concept in greater depth. This requires extensive research but is beyond the scope of the current study though future work on these questions is recommended.

The existence of these different dimensions is consistent with the view that sustainable development is a complex and abstract concept. Using these dimensions of the concept as a framework for teaching might enrich the learning and teaching process and potentially give students an in-depth insight into the nature of sustainable development. Furthermore the different dimensions of sustainable development as perceived by the students can bring about diversity as students begin to 'think outside the box' and thereby moulding engineers who are equipped with the necessary skills and knowledge to work in a diverse and complex environment.

## 6.4. Exploration of sustainable development as a threshold concept

From both the interviews and surveys, there was evidence to suggest that the concept of sustainable development is regarded as a threshold concept. The figure below shows the percentage of respondents who experienced the different threshold concept characteristics and it is quite evident that sustainable development is transformative, integrative, irreversible and troublesome.

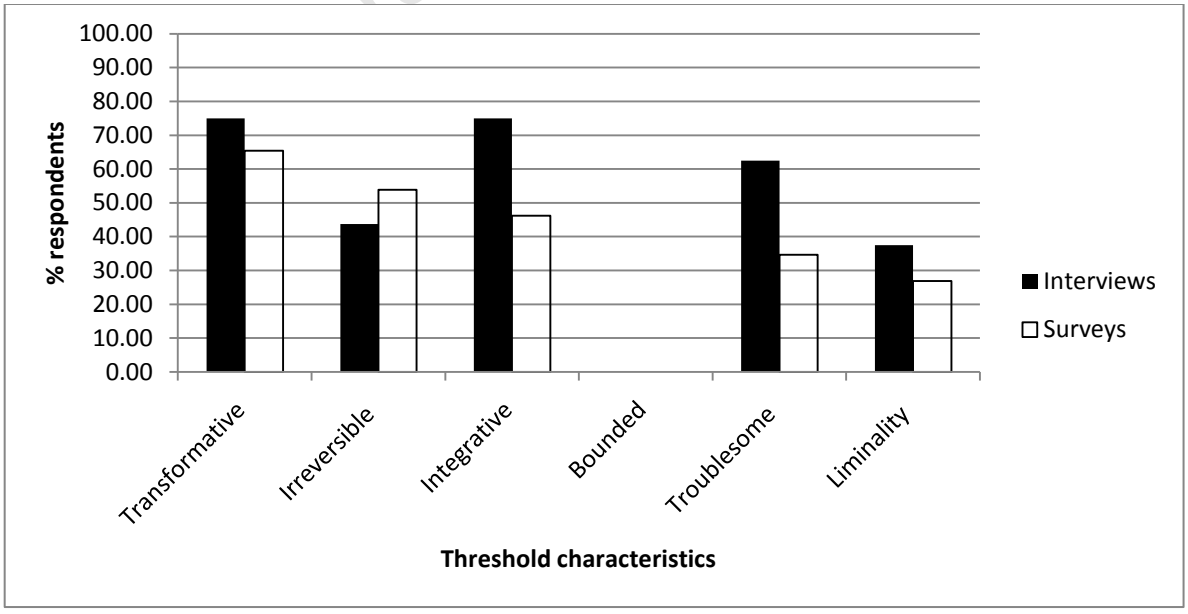


**Figure 8: Percentage breakdown for students' experiences**

Generally, the results from both the interviews and survey correlate though the characteristics emerge stronger in the interviews. This could be due to the mode of data collections as interviews allow for probing and also the population sampled. The analysis also revealed that students' learning experiences vary but that the learning process of sustainable development as a concept is complex and is a transformative experience.

The statement that sustainable development is an integrative concept implies that sustainable development is about taking disparate and seemingly unrelated elements together in an attempt to create a cohesive whole. This also implies that sustainable development is a continuous process that requires engineers to constantly reassess their actions allowing for adaptability of their solutions to specific contexts. There was a strong correlation between three of the threshold concept characteristics, namely transformative, integrative and troublesome. This was expected as the characteristics are 'interwoven'. Davies and Mangan (2007) state that "a concept that integrates prior understanding is inevitably transformative as it changes a student's perception of their existing knowledge and thus is more likely to be irreversible, because it holds together a learner's thinking about many different phenomena" (p. 712). A concept that is transformative is also likely to be troublesome as it involves moving into new territory and thus the correlation is expected.

No evidence from the data analysis was obtained to suggest that the concept of sustainable development is bounded. This is expected as not all threshold concepts are bounded; this is consistent with the work of Meyer and Land (2003) who state that "threshold concepts are possibly often (though not necessarily always) bounded" (p. 6). In the case of sustainable development, the characteristic of boundedness cannot apply as the concept is multidisciplinary and therefore the boundaries of the concept cannot be defined.

The analysis also revealed that most of the students expressed varying opinions towards the future in relation to sustainable development challenges. A few of the respondents were optimistic but the majority had pessimistic viewpoints. In their discussions, there is a sense of frustration, anxiety and sadness about the environmental crisis and the challenges that have arisen as a result of unsustainable practices. These

findings are consistent with the literature on threshold concepts. According to Eckerdal et al. (2006) students often exhibit emotional reactions while learning threshold concepts. These feelings range from fear, hatred, frustration, depression and euphoria at finally grasping the concepts (Eckerdal, et al., 2006). Kagawa (2007) also states that it is common for students to express these negative feelings and states that this has a significant implication for engineering education. According to Kagawa (2007), traditional engineering education does not take into account the "emotional impacts of global issues on students and thus it is imperative to develop pedagogies that provide hope, liberation and empowerment to students" (p. 334).

The study also examined the notion of liminality. From the results, it is clear that the process of understanding sustainable development is complex and sometimes difficult for students. The learning experience for each student varies as each student navigates the liminal space differently. Because of this, the teaching of sustainable development should accommodate each individual student. Characterizing sustainable development as a threshold concept raises the questions on how threshold concepts should be used as a framework for learning and also if the liminal space can be a useful way of determining how students understand sustainable development.

## 6.5. Students' views and experiences of learning about sustainable development

The views and experiences of learning about sustainable development from students' perspectives are important. This is because educational research has shown that the success in student learning positively correlated with a student's prior knowledge of the subject and to their perceived personal competence of the topic. As discussed in section 2.1 and 2.2, success of a student's learning correlates with how well the student feels they have understood the topic, how interesting they consider the topic to be and also how relevant and useful they consider the given concept to be (Van Rossum & Schenk, 1984).

From the interviews a few of the respondents stated that they felt that there was insufficient exposure on the concept during their undergraduate curriculum and that they were unable to relate it to their lives. This attests to the complexity of sustainable

development and lends support to the argument that sustainable development should be taught in an interactive way, as argued by von Blottnitz (2006)- "eloquently delivered lectures on the need for sustainable development may convince students of the importance of something, which, when asked to define, they can only do by citing the Brundtland definition" (von Blottnitz, 2006, p. 917). In addition, he argues that student engagement is a pre-condition for deep approaches to learning about a complex concept such as sustainable development and would facilitate the development of responsible change agents who work towards creating a sustainable society (von Blottnitz, 2006). Interestingly then, the students who have all completed the course designed by von Blottnitz to be an active learning experience are generally in a position to talk about sustainable development well beyond the Brundtland definition, yet often still feel ill-prepared to act on their understanding. An inspection and review of the 4th year Business, Society and Environment course, from the perspective of sustainable development being a threshold concept, might thus be in order.

From the students' responses discussed in section 4.3, it is clear that students think and feel that the government and universities play a vital role in promoting sustainable development. This, the students argue is because higher education institutions have the potential to significantly contribute to the global efforts of addressing the environmental challenge discussed in section 1.1. The major implication of this is that universities and the government should work in a collaboration to raise awareness on sustainable practices. Carew (2004) argues that higher education institutions have three major roles to play - the operational role; leadership role and the advocate role. According to Carew (2004) the university has an operational role that requires the university to actively minimise resource consumption in their daily operations and to address issues such as social injustice. The leadership role implies that universities should lead by example and show that while their operations are financially viable, they are socially responsible and environmentally friendly (Carew, 2004). This can be achieved by publicising the universities' working examples. Further, she states that the role of advocate requires universities "to equip and inspire individuals to enact sustainability throughout and for the duration of their personal and professional lives" (Carew, 2004, p. 160). Engaging students in discussions on sustainable development issues, creating opportunities for students to be involved in green initiatives on campus

and also in the surrounding communities and promoting open discussions on sustainable development will help students have rich learning experiences and mould students who think with sustainable principles in mind.

## 6.6. Recommendations for future work

The concept of sustainable development covers a vast literature and thus there are many opportunities for growth and change within engineering education. This means that research should be conducted to explore how best the concept of sustainable development can be taught so as to mould engineers who are conscious of sustainable development. This can be done by investigating learning techniques that engage students and also hold by exploring the idea of threshold concepts especially the notion of liminality. Research should explore how students cross the threshold as this gives insights into the students' progression. Some questions on what prompts the change that facilitates the student to cross the threshold and how the undergraduate curriculum can further support this need to be further investigated.

## 6.7. Summary

A general discussion of the results outlined in Chapter 4 and Chapter 5 was presented in this final chapter. From the discussion, it is evident that there is a need for a deeper understanding of sustainable development amongst engineering students. Secondly the study revealed that most students strongly associate sustainable development with environmental issues rather than embracing a holistic understanding. This means engineering education needs to address the interconnectedness and multidisciplinary nature of sustainable development to help students understand how complex the concept is. Thirdly engineering students have varying dimensions of sustainable development and the diverse conceptions attest to how complex the concept of sustainable development is. Sustainable development can be thought of, and should be taught as, a threshold concept as it exhibits most of the appropriate characteristics – a slight complication for the content-focussed curriculum designer.

# Appendix I: Interview protocol

The researcher used the following questions as a guideline in the semi-structured interviews conducted. The form and sequence of the questions were determined by the responses given by the respondents[3].

1. Can you explain what you understand about sustainable development?
2. How is the idea of sustainable development important to you personally and professionally?
3. Has your idea of what SD is evolved with time or have you always had the same idea?
4. Where did you get your current knowledge of SD come from?
5. How did your knowledge of SD relate to your other knowledge you already had or to new knowledge?
6. Can you remember how the learning process felt? Was it easy or difficult for you and why?
7. Were there any barriers to learning about SD?
8. Were there any uncomfortable spaces or not?
9. How well do you think you have you understood SD?
10. Has the knowledge of SD changed your view of chemical engineering and what role do you think chemical engineers play in implementing SD?
11. Can you tell me what you think about SD in South Africa? Are we there yet or do you feel like there's still a lot to be done?
12. What role do you think the government, universities etc. should play an important role in implementing SD and how?
13. Are you interested in learning more about SD and what is the relevance of sustainability to your future career?
14. Do you practice sustainability? If so, what have you done to implement SD in to your life and how has grasping the concept of SD impacted your life?
15. Do you have any other comments you would like to make?



[3] SD is an abbreviation for sustainable development

# Appendix II: Interview summaries

**Henry**

The concept of sustainable development is of great importance to Henry. He describes sustainable development as an ideal that gives us completely different ways and better ways of doing what we should be doing. It is about tackling problems in ways that benefit humans without damaging the environment. Since he first encountered the concept, he says his understanding has changed from seeing it as an environmental challenge to the realization that it is a multidisciplinary concept that requires economists, engineers, geographers and social scientists to work together to achieve it. Henry says the Brundtland definition was instrumental as it brought together different aspects for him and reinforced the idea of systems thinking. It has led to a transformation within his lifestyle and career path choices. Some of these changes include cycling, recycling, composting, installing a solar heater and grey water system all in an attempt to reduce his carbon footprint.

**Janet**

Janet describes sustainable development as economic growth aimed at improving the quality of life within environmental constraints. Initially Jane considered sustainable development to be a buzzword but her understanding of the concept has evolved from reciting the Brundtland definition to a deeper understanding. Understanding the concept has led Janet to have a changed view of chemical engineering practice and also transformed her way of life. Janet also states that the concept does not conflict with prior knowledge but fits in properly especially with the guiding principles of chemical engineering. Janet states that the sustainable development concept is worrying for her. She is worried about the impact she has on the environment and has implemented changes to try and minimize her impact. As a result, Janet recycles, saves water and has cut down on air travel. She says she prefers walking, cycling or using public transport as opposed to driving her own car. Janet also states that these changes within the engineering education should be implemented to ensure upcoming engineers always think with sustainable development in mind.

**Grace**

According to Grace, sustainable development is a bridge of science, society and maybe economics. It is about ensuring that the needs of our generation are met with no negative environmental impact and without creating too much conflict about the scarcity of resources so future generations have enough. For Grace, sustainable development is also about addressing social issues and this can only be achieved by economists, social scientists and engineers working together towards a common goal because the concept is very complex and is an interdisciplinary science. Grace states that learning about sustainable development has been transformative and has also added up parts and shed some light on the whole engineering practice. Because of the complexity of the subject, Grace admits that she still has a lot to learn. The concept is also bothersome for Grace because although she is aware of the changes she is not in a position to implement. Grace also says that although she would like to work for a company that is driven by sustainable development principles, other factors have to be considered as she cannot afford to be too selective as there are not many jobs available to foreigners.

**Allan**

Allan describes sustainable development as a process of finding a region where a harmonious relationship between your social, economic and environmental considerations exists. It is economic growth that always considers the environmental and social consequences of any actions. For Allan, sustainable development is also a way of life. Allan supports Mebratu's model of sustainable development as he feels that the social, economic and environmental sphere are co-dependent as human society cannot survive without the environment and likewise the economic system is dependent on the human and environmental systems. He states that grasping the concept has altered his perceptions of engineering and it has also changed some of his habits. He also states that the concept ties in strongly with other knowledge from other courses. However, initially for Allan sustainable development was just a buzzword but the concept came clearer after reading and learning more about it. According to Allan, sustainable development should be taught as the framework for engineering practice rather than as an afterthought so as to mould engineers who question the consequences of their actions and design.

**Lionel**

Lionel uses the definition given by Goodland and Daly (1996) and explains it is development with no growth in material or energy throughputs beyond what can be absorbed by the environment. Lionel states that initially, it was a fuzzy idea that he was able to discuss after reading up in literature and prolonged learning about the concept. He says that the knowledge of sustainable development has changed his view of the chemical engineering practise and the role that engineers play. He is now more aware of his impact and has made the transition to a more sustainable way of living. Lionel further states that the concept assimilates the different chemical engineering principles and to demonstrate this he uses an example of how in plant design you consider mass and energy balances, health, safety, economic aspects, thermodynamics and impacts of the designed process on the environment and society which is basically what sustainable development is about.

**Constance**

Constance defines sustainable development as the efficient and responsible resource use so as to allow future generations to flourish. She says sustainable development is about limiting development to prevent overharvesting of resources. She states that sustainable development is important to her both personally and professionally. According to Constance, understanding what sustainable development is has made her more conscious of the impact she has on the environment and society in general. This she says has led her to live in a more sustainable way by reducing her fuel consumption, sorting her waste and generally opting for environmentally friendly products. She states that she is able to relate her knowledge of sustainable development to the fundamental principles of chemical engineering especially process optimization. For Constance, the concept of sustainable development conflicts with some of her lifestyle choices especially when it comes to buying products that damage the environment and the issue of driving. She indicates that implementing changes is difficult because there is no proper infrastructure to recycle water, create a compost heap and or dispose of waste effectively.

**George**

George defines sustainable development as being about optimizing process through the use of innovative technology to reduce consumption and the amount of resources used.

Further, he states that it is about considering the environmental and social impacts of our decisions and actions. According to George, the concept of sustainable development does not conflict with prior knowledge but rather provides a bigger picture and a new way of tackling problems. He says his understanding of sustainable development has been gradual and over a long period of time. He further states that his understanding has changed his views and perceptions of engineering and development. George attests to the troublesomeness of the concept. He says the finds it is difficult to implement changes as sometimes there is no proper infrastructure for it and also because there is no clear answer as to how to implement it. However, George strongly believes that achieving sustainable development is a team effort and can be only be attained by various stakeholders working together for the common good.

**Portia**

For Portia, sustainable development is about using resources in a responsible manner to make certain that future generations have the ability and capacity to meet their needs. She further declares that sustainable development is about optimizing processes and innovative design so as to minimize pollution and environmental degradation. In her interview, Portia stated that sustainable development is a link between various disciplines. She states that understanding sustainable development involves a mindset change and has also changed some of her habits. She also states that this transformation is difficult because it involves breaking old habits and developing new ways of doing things. Portia also states that for sustainable development can be achieved if everyone work together to build sustainable nations.

**Lethukuthula**

Lethukuthula describes sustainable development as the integration of three issues i.e. social, economic and environmental issues. She also states that it is about investing in optimum processes that do not deplete natural resources. It is about finding renewable substitutes and resource management. She says sustainable development is important and has transformed her views on the role that she can play as an engineer to address the sustainable development challenge and the career she wants to pursue. She also states that her knowledge of sustainable development ties in with the fundamental principles of chemical engineering especially in process design and control. Lethukuthula declares that she has substantial knowledge of the concept but does not

consider herself to be an expert on the subject as she learns something new each day. Despite her understanding, she says she has not implemented any changes in her life as there is no infrastructure to do it, it is time-consuming and she is also too set in her ways to welcome any change. She also says eradicating poverty and changing mindsets is the first step to achieving sustainable development.

**Tatenda**

Sustainable development for Tatenda means maintaining the balance between ecological, social and financial systems to ensure resources are not overharvested. Her interest in the concept arose from the many adverts on television advising people on energy consumption and importance of living sustainably. Since she has been learning about sustainable development, Tatenda has had a transformed view of the engineering industry and practice. As an engineer, she states that sustainable development is about optimizing processes to reduce the harmful impacts on the environment by ensuring process emissions and effluents are not harmful. She also states it is important that engineers move from processes that are designed with economic gain in mind but also consider the environmental and social implications of their design. The concept is troublesome for Tatenda because it conflicts with some of the things that she's been taught and because sometimes she is unable to relate sustainable development in her everyday life.

**Harry**

Harry description of sustainable development is primarily concerned with responsible resource usage and optimization of processes to reduce the destruction on the environment and also minimizing waste effluent, emissions and energy consumption. To elaborate his point, he describes the differences between strong and weak sustainability and states that sustainable development is concerned with more durability. Harry acknowledges that initially sustainable development was just a word that was thrown around but since learning about it, he has developed a deeper understanding. Moreover, he feels that achieving sustainable development is an attainable goal. For this change, he argues that a change of mindset is imperative. Understanding about sustainable development had made Harry more aware of the impacts of his actions and also an increased awareness of social and environmental issues. Harry states that sustainable development principles can be easily incorporated

into engineering practice as sustainable development goes hand in hand with costs and optimization and is implicitly included within mass and energy balances. For Harry, sustainable development is a way of life; it is about making conscious decisions about waste disposal, what products to use and consumption patterns.

**Pride**

Pride describes sustainable development as the efficient resource use in a manner that takes into consideration environment impacts and the needs of future. She states that her understanding of sustainable development has made a lot of things clearer. She states that her knowledge does not contradict earlier knowledge that she had but rather explains why certain things are done such as recycling and conservation of water and energy. She says that the concept of sustainable development is wearisome because even though she has had the relevant theory, she is not always sure what to do to implement the changes towards living a sustainable life. She attributes laziness as one of the things that hinders her from actually taking action and gives an example of how she would leave the television on because she is too lazy to get up and switch it off at the mains. She also feels that the concept of sustainable development should be introduced at an earlier stage within the undergraduate curriculum to allow for maximum learning. She says this would enable students to use sustainable development as a framework on which their decisions especially in industry are based. She further states that she thinks sustainable development is of great importance though it does not really factor in her personal life and does not influence her career choices.

**Sizwe**

Sizwe describes sustainable development as optimizing processes to make certain that minimum resources are consumed. He states that sustainable development is about longevity and about ensuring access of the same amount of resources to both present and future generations. He further states that sustainable development is about finding technologically new ways of doing things. Whilst Sizwe states that he is interested in learning more about sustainable development, he states that he's indifferent to the challenges of sustainable development and thinks the concept is only important for future generations. When asked how his knowledge of what sustainable development links up to other knowledge, he states that it links up with prior knowledge provided that it is incorporated in the beginning. He says this is because sustainable development

as a framework determines what must be done and also how best it should be done. For Sizwe, grasping the concept of sustainable development has been transformative in that he is more conscious about his use of water and electricity and also made him aware of the importance of sorting out his waste. However, he states that this transformation is not easy and happens over time. He also states that some aspects of sustainable development conflict with his personal choices.

**Kagiso**

Sustainable development for Kagiso means using resources effectively so that future generations have their share of resources. He further defines sustainable development as optimizing processes to try and minimize emissions and waste effluent. Kagiso declares that he supports the weak sustainability approach and gives an example of the mining industry. He says whilst the mining industry uses non-renewable resources and results in environmental degradation, the economic gain outweighs the negative ecological damage. Although Kagiso has been exposed to sustainable development during his classes, he states that initially he had a partial understanding of the concept and what it entails. He feels that with prolonged engagement with the concept, he might get a better understanding that will be beneficial especially in his career. Kagiso affirms that what he has managed to grasp of the concept has made him more aware of his impact especially where energy, water and resource consumption is concerned. This has resulted in him opting for more environmentally friendly products and choosing to walk short distances instead of driving. He states that these changes are long-term as they have become habits that are ingrained in him. According to Kagiso, the transition to a sustainable way of living is difficult especially in his personal life. As an example he states that the idea of choosing an eco-efficient car over brand is one such conflict.

**Patience**

Patience uses the dominant conceptualization of sustainable development of the three intersecting circles to explain what sustainable development means. However, she sees sustainable development as a standalone concept that does not fit in within the engineering curriculum and practice. Even though Patience fails to see the relevance of sustainable development, she states that she has changed some of her habits and now recycles, conserves water and energy. She states that this change has occurred more

because of the high prices of commodities and an increase in the water and electricity tariffs.

**Thando**

Thando defines sustainable development as using resources in a conscious way so as to leave enough resources for future generations to survive. She sees sustainable development as developing innovative technology that uses resources efficiently without producing by-products or effluents that are harmful to the environment. According to Thando, sustainable development is not only about financial gain and looking at ways of mitigating environmental problems that arise from engineering activities but about also addressing the social issues that are faced by the surrounding communities. For Thando, the concept of sustainable development has changed the way she views engineering and has also led her to make conscious decisions about the kind of products she buys and her career aspirations. She states that this transformation though difficult has been life-changing and feels it is a permanent fixture in her life. Thando believes she can make a difference both as an individual and as an engineer and thus she is constantly reading more on the subject to increase her knowledge. Thando states that the concept is interconnected as it involves social, financial, environmental and political issues.

# Appendix III: Survey response sample

| 1. What is your gender? |
|---|
| Male |

| 2. Which of the following courses are you enrolled for? |
|---|
| CHE4048F |
| CHE4024F |
| CHE4042F |

| 3. How do you rate your knowledge of the following topics? | | | | |
|---|---|---|---|---|
| | Not heard of (1) | Heard of but cannot explain (2) | Have some knowledge (3) | Know a lot (4) |
| Acid rain | | | X | |
| Air pollution | | | X | |
| Biodiversity | | | X | |
| Climate change | | | | X |
| Deforestation | | | X | |
| Depletion of natural resources | | | X | |
| Desertification | | X | | |
| Ecosystems | | X | | |
| Global warming | | | X | |
| Ozone depletion | | | X | |
| Photochemical smog | | X | | |
| Salinity | | X | | |
| Solid waste | | | X | |
| Water pollution | | X | | |

| 4. List 3 words that come to mind when you hear the term sustainable development |
|---|
| clean green long-term |

| 5. Choose a maximum of 5 responses and rank them in order of which you feel best describes sustainable development (where 1 is the best definition) | | | | | |
|---|---|---|---|---|---|
| | 1 (1) | 2 (2) | 3 (3) | 4 (4) | 5 (5) |
| i.Environmental protection & resource management | | | X | | |
| ii.Provision of clean air, water and education | X | | | | |
| iii.Ethics,social justice & participation in decision making | | X | | | |
| iv.Environmental accounting & ecoefficiency | | | | X | |
| v.Efficient use of resources through innovative technology | | | | | X |
| vi.Intergenerational and intragenerational equality | | | | | |
| vii.Fundamental changes in consumer behavior & consumer patterns | | | | | |
| viii. Poverty alleviation, provision of housing and basic service delivery | | | | | |

**6. State wheather you agree or disagree with these statements below.**

| | Strongly disagree (1) | Disagree (2) | Neutral (3) | Agree (4) | Strongly agree (5) |
|---|---|---|---|---|---|
| 1. My understanding of sustainable development has made me more frugal and aware of the impact I make on the environment. | | | | | X |
| 2. Sustainable development relates to courses I have learnt and ties in with the fundamental principles of mass & energy balances and process design. | | | | X | |
| 3. Now that I understand what sustainable development is, I can't go back to viewing things in the same way. | | | X | | |
| 4. When I buy a car, the brand will be more important than ecoefficieny. | | | | X | |
| 5. Even though I have been exposed to the concept of sustainable development in class, I still fail to see how they can be applied to chemical engineering | | X | | | |
| 6. Initially I struggled with the concept of sustainable development as it was a fuzzy idea but now I have a better understanding of what it entails. | | | X | | |

**7. Which of these topics would you be interested in learning more about within the chemical engineering curriculum?**

| |
|---|
| Sustainable design |
| Renewable energy technologies |
| Environmental Regulations |

**8. Is working towards sustainable development important?**

| |
|---|
| Yes, it is a top priority |

**9. How do you react to the challenge of sustainable development? (tick the responses that apply to you)**

| |
|---|
| Take action i.e recycle, turn off lights etc. |

# Appendix IV: Ethics approval

## EBE Faculty: Assessment of Ethics in Research Projects

Any person planning to undertake research in the Faculty of Engineering and the Built Environment at the University of Cape Town is required to complete this form before collecting or analysing data. When completed it should be submitted to the supervisor (where applicable) and from there to the Head of Department. If any of the questions below have been answered YES, and the applicant is NOT a fourth year student, the Head should forward this form for approval by the Faculty EIR committee: submit to Ms Zulpha Geyer (Zulpha.Geyer@uct.ac.za; Chem Eng Building, Ph 021 650 4791). Students must include a copy of the completed form with the thesis when it is submitted for examination.

Name of Principal Researcher/Student: Lesley Sibanda Department: Chemical Engineering

If a Student: Degree: MPhil Chem Eng Supervisor: Assoc Prof Jenni Case

If a Research Contract indicate source of funding/sponsorship:

Research Project Title: An investigation into the conceptions of sustainable development held by chemical engineering graduates

**Overview of ethics issues in your research project:**

| | | |
|---|---|---|
| **Question 1: Is there a possibility that your research could cause harm to a third party i.e. a person not involved in your project)?** | YES | NO X |
| **Question 2: Is your research making use of human subjects as sources of data?** If your answer is YES, please complete Adcendum 2. | YES X | NO |
| **Question 3: Does your research involve the participation of or provision of services to communities?** If your answer is YES, please complete Adcendum 3. | YES | NO X |
| **Question 4: If your research is sponsored, is there any potential for conflicts of interest?** If your answer is YES, please complete Adcendum 4. | YES | NO X |

If you have answered YES to any of the above questions, please append a copy of your research proposal, as well as any interview schedules or questionnaires (Addendum 1) and please complete further addenda as appropriate.

**I hereby undertake to carry out my research in such a way that**

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would corstitute plagiarism.

Signed by:

| | Full name and signature | Date |
|---|---|---|
| Principal Researcher/Student: L Sibanda | Lesley Sibanda | 5 July 2010 |

This application is approved by:

| | | |
|---|---|---|
| Supervisor (if applicable): Hven Blottnitz | | 23/06/2010 |
| HOD (or delegated nominee): Final authority for all assessments with NO to all questions and for all undergraduate research. | | |
| Chair : Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the above questions. | | 8/8/2010 |

**ADDENDUM 1:**
Please append a copy of the research proposal here, as well as any interview schedules or questionnaires:

**ADDENDUM 2:** To be completed if you answered YES to Question 2:

It is assumed that you have read the UCT Code for Research involving Human Subjects (available at http://web.uct.ac.za/depts/educate/download/uctcodeforresearchinvolvinghumansubjects.pdf) in order to be able to answer the questions in this addendum.

| | | |
|---|---|---|
| 2.1 Does the research discriminate against participation by individuals, or differentiate between participants, on the grounds of gender, race or ethnic group, age range, religion, income, handicap, illness or any similar classification? | YES | NO X |
| 2.2 Does the research require the participation of socially or physically vulnerable people (children, aged, disabled, etc) or legally restricted groups? | YES | NO X |
| 2.3 Will you not be able to secure the informed consent of all participants in the research? (In the case of children, will you not be able to obtain the consent of their guardians or parents?) | YES | NO X |
| 2.4 Will any confidential data be collected or will identifiable records of individuals be kept? | YES X | NO |
| 2.5 In reporting on this research is there any possibility that you will not be able to keep the identities of the individuals involved anonymous? | YES | NO X |
| 2.6 Are there any foreseeable risks of physical, psychological or social harm to participants that might occur in the course of the research? | YES | NO X |
| 2.7 Does the research include making payments or giving gifts to any participants? | YES | NO X |

If you have answered YES to any of these questions, please describe below how you plan to address these issues:

2.4. All confidential data will be stored in encrypted documents, and only the researcher (in this case me) will have the passcodes to the relevant documents.

**ADDENDUM 3:** To be completed if you answered YES to Question 3:

| | | |
|---|---|---|
| 3.1 Is the community expected to make decisions for, during or based on the research? | YES | NO |
| 3.2 At the end of the research will any economic or social process be terminated or left unsupported, or equipment or facilities used in the research be recovered from the participants or community? | YES | NO |
| 3.3 Will any service be provided at a level below the generally accepted standards? | YES | NO |

If you have answered YES to any of these questions, please describe below how you plan to address these issues:

**ADDENDUM 4:** To be completed if you answered YES to Question 4

| | | |
|---|---|---|
| 4.1 Is there any existing or potential conflict of interest between a research sponsor, academic supervisor, other researchers or participants? | YES | NO |
| 4.2 Will information that reveals the identity of participants be supplied to a research sponsor, other than with the permission of the individuals? | YES | NO |
| 4.3 Does the proposed research potentially conflict with the research of any other individual or group within the University? | YES | NO |

If you have answered YES to any of these questions, please describe below how you plan to address these issues:

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