Perspectives on engineering education in universities and its contribution to sustainable human development in Germany and South Africa

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This thesis is submitted in accordance with the requirements for the PhD in Development Studies in the Centre for Development Support, Faculty of Economic and Management Sciences at the University of the Free State

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Table of contents

List of tables and figures

List of acronyms and abbreviations

ANC	African National Congress
BMBF	*Bundesministerium für Bildung und Forschung* (Federal Ministry of Education and Research)
CAESER	Conference of European Schools for Advanced Engineering Education and Research
CDU	*Christlich Demokratische Union Deutschlands* (Christian Democratic Union of Germany)
CHE	Council on Higher Education
CHED	Centre for Higher Education Development
CRHED	Centre for Research on Higher Education and Development
DEAT	Department of Environmental Affairs and Tourism
DHET	Department of Higher Education and Training
DFG	*Deutsche Forschungsgemeinschaft* (German Research Association)
ECSA	Engineering Council of South Africa
ECTs	European Credit Transfers
EFA	Education for All
EHEA	European Higher Education Area
ESD	Education for Sustainable Development
EUR-ACE	European Accredited Engineer
DESD	Decade of Education for Sustainable Development
GER	Germany
HDRs	Human Development Reports
HRK	*Hochschulrektorenkonferenz* (German Rector's University Council)

IEA	International Engineering Alliance
IISD	International Institute for Sustainable Development
IUCN	International Union for Conservation of Nature
MDGs	Millennium Development Goals
NP	National Party
NCHE	National Commission on Higher Education
PLE	Project-led Education
SA	South Africa
SEFI	*Société Européenne pour la Formation des Ingénieurs* (European Society for the Formation of Engineers)
SPD	*Sozialdemokratische Partei Deutschlands* (Social Democratic Party of Germany)
STEM	Science, Technology, Engineering and Mathematics
SDGs	Sustainable Development Goals
UB	*Universität Bremen* (Bremen University)
UCT	University of Cape Town
UN	United Nations
UN DESA	United Nations, Department of Economic and Social Affair
UNDP	Development Programme
UNESCO	United Nations Educational, Scientific, and Cultural Organisation
VDI	*Verein Deutsche Ingenieure* (Association of German Engineers)
WCED	World Commission on Environment and Development
WSSD	World Summit on Sustainable Development

Declaration

I, Mikateko Höppener declare the following:

i. The Doctoral Degree research thesis that I herewith submit for the Doctoral Degree qualification: Philosophiae Doctor in Development Studies at the University of the Free State is my independent work, and that I have not previously submitted it for a qualification at another institution of higher education.
ii. I am aware that the copyright is vested in the University of the Free State.
iii. All royalties as regards intellectual property that was developed during the course of and/or in connection with the study at the University of the Free State will accrue to the University of the Free State.

Signed:

Date: 01 February 2016

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Abstract

Most literature on higher education and engineering education in particular, is based on data gathered from the global North, written from global North perspectives. Comparatively few studies focus on normative accounts of education for sustainable development based on data from developing countries, and written from global South perspectives. While there is value in exploring views from different contexts separately, what is original and significant about the work of this thesis is the examination of these perspectives together, combining a normative approach with original empirical work, and recognising that they are different outlooks on the same issue: how engineering education in universities contributes to sustainable human development. Instead of dichotomising global North/South perspectives, the thesis combines the views of individuals whose teaching and learning, higher education and/or professional careers in engineering have taken place in the global North (Germany) and global South (South Africa) for its empirical base. Specifically, the viewpoints of 18 masters students and 10 lecturers from engineering faculties at Universität Bremen (Germany) and the University of Cape Town (South Africa), as well as 10 engineering employers from both countries, were explored using qualitative methods (semi-structured interviews and focus group discussions). The research questions addressed in this thesis relate to how engineering education in universities enlarges the capabilities of engineering graduates, so that they might become agents of sustainable human development.

The perspectives, often surprisingly similar across the two countries, offer contrasting and critical views on the assumption that society is in pursuit of an agenda for 'sustainability' that is valuable for all, and of future engineers' roles in determining such an agenda. The findings also show that the participants perceive degrees of ambiguity about the extent to which engineers are educated to use their skills, knowledge, and effective power as professionals who contribute to solving human development and sustainability challenges in a just way. That is, in a way that explicitly prioritises poverty reduction and advances social justice. Reflecting on these perspectives from Germany and South Africa, the thesis considers what justice-based, capability-inspired engineering education might look like, if it is to enhance future engineers' opportunities to use their agency to practice public-good engineering for human development.

Samevatting

Die meeste literatuur oor ingenieurswese opvoeding is gebaseer op data ingesamel vanaf die globale Noordelike perspektiewe. Daar is relatief min studies wat hul aandag fokus op normatiewe weergawes van die globale Suide rakende ingenieurswese uitkomste, ingenieurswese opvoeding hervorming, of ingenieurswese opvoeding vir volhoubare ontwikkeling. In ŉ poging om ryker, meer genuanseerde weergawes van hierdie kwessies te bied, kombineer hierdie tesis die perspektiewe van individue wie se onderwys, leer of professionele loopbane in ingenieurswese in die globale Noorde (Duitsland) en die globale Suide (Suid-Afrika) plaasgevind het. Meer spesifiek, die tesis ondersoek, beskryf en stel naas mekaar die perspektiewe van 18 meesters studente en 10 dosente van ingenieursfakulteite aan die Universiteit van Bremen (Duitsland) en die Universiteit van Kaapstad (Suid-Afrika), sowel as 10 ingenieur werksverskaffers van beide lande. Kwalitatiewe metodes (semi-gestruktureerde onderhoude en fokus groep besprekings) is gebruik om data in te samel wat die empiriese basis van die tesis vorm. Die navorsingsvrae aangespreek in hierdie tesis kyk hoe ingenieurswese opvoeding in universiteite geleenthede vir ingenieurs vergroot om as agente vir volhoubare menslike ontwikkeling te funksioneer, asook hoe die waarde van volhoubare ontwikkeling aangespreek word in die kurrikula en pedagogiese ordening wat ingenieurswese programme in internasionale kontekste karakteriseer.

Die perspektiewe bied kontrasterende en kritiese sieninge oor die aanname dat die samelewing ŉ 'volhoubaarheidsagenda' nastreef wat waardevol vir almal is, asook toekomstige ingenieurs se rolle om so ŉ agenda te bewerkstellig. Die perspektiewe bied ook genuanseerde begrippe van die uitdagings wat universiteite in die gesig staar om ingenieurs op te lei wat hul vaardighede, kennis en effektiewe mag as professionele individue kan gebruik om uitdagings rakende menslike ontwikkeling en volhoubaarheid in ŉ geregtelike manier aan te spreek. Dit is, op ŉ manier wat eksplisiet armoede bevegting en sosiale geregtigheid prioritiseer en bevorder. Die tesis oorweeg die implikasies van hierdie perspektiewe deur die lens van die vermoënsbenadering en menslike ontwikkeling paradigma om sodoende te illustreer hoe ingenieurswese opvoeding potensieel kan lyk as dit toekomstige ingenieurs se agentskap ontwikkel om volhoubare menslike ontwikkeling ten goede van die gemeenskap te bevorder.

Part I

Background, context, and theoretical foundations of the study

Chapter 1

Introduction, background, and conceptual perspective

1.1 Background: Sustainable development

Historically, universities have played a role in transforming societies by educating decision-makers, leaders, entrepreneurs, and academics who serve the public good (Lozano, 2013). However, utilitarian and human capital perspectives tend to dominate the way universities are run in current times, resulting in the development of unbalanced, over-specialised, and mono-disciplinary graduates (Lozano, 2013) who primarily see education as a means to employment. While education can and should enhance human capital, people and societies also benefit from education in ways that exceed its role in preparing individuals for commodity production in industry (Boni & Walker, 2013). Also, an educational focus on employability and jobs does not tell much (if anything) about the quality of work, or whether or not people are treated fairly and with dignity at work, or whether they are able to do and to be what they have reason to value as professionals or citizens (Boni & Walker, 2013). As Boni & Walker (2013) posit, a human development perspective, with its core values of well-being, participation, empowerment, and sustainability could be a good framework to rethink and reimagine a different vision of the university, beyond only the instrumental goal to prepare people as a workforce.

The last few decades have seen a rise in the promotion of education for sustainable development (ESD) as opposed to a primary focus on education for employment, which has created the impetus for sustainability to become a new paradigm in the complex systems of universities (De La Harpe & Thomas, 2009; Karatzoglou, 2013; Lozano, 2013; Ramos, Caeiro, Hoof, Lozano, & Huisingh, 2015). The United Nation's (UN) declaration of the years 2005-2014 as the 'Decade of Education for Sustainable Development' (DESD) is a good example of an initiative to promote education and learning as the basis for a more sustainable world. The major goals of the DESD were to embed sustainable development into all learning spheres, reorient education and develop initiatives that showcase the special role and contribution of education in our pursuit of sustainable development (Tilbury & Mula, 2009). Whereas relevant interest in the DESD has been demonstrated at a regional level and by some nations, the conceptual vagueness of sustainable development (Mebratu, 1998) and the diversity of responses to ESD do not always invite policymakers or practitioners to engage with this agenda (Lozano, 2013). Despite these challenges, the DESD has raised expectations amongst ESD stakeholders, who see this platform as a good opportunity not only to embed ESD at all education levels but also to influence government decisions and to move towards social and economic systemic change (Lozano, 2013). As such, promoting ESD is about engaging and empowering people in sustainable development, through seeking people's commitment to sustainable development and giving them power to make decisions and bring about changes that are consistent with sustainable development principles (Tilbury & Mula, 2009).

Early discussions on sustainable development began taking place in the 1970s, prompted by concerns raised by the International Union for Conservation of Nature (IUCN) and events such as the 1972 UN Conference on Human Environment (Lélé, 1991; Mebratu, 1998; Robert, Parris, & Leiserowitz, 2005). The IUCN sought to bring public attention to ideas of conservation, with an emphasis that species and ecosystems should be used in a manner that allows them to go on renewing themselves indefinitely. The union's 1980 World Conservation Strategy showed how efforts to conserve nature and natural resources needed to be integrated with a clear understanding of their essential role in human flourishing (see IUCN, 1980).

Debates about the link between finite environmental resources and development slowly began to emerge, which brought about notions that the form of economic expansion would have to be altered (Mebratu, 1998). So the idea of 'sustainable development' essentially arose from apprehensions related to the over exploitation of natural and environmental resources, the negative impact this would have on processes of production and industrialization, and hence on economic activity in the future. Additionally, questionable outcomes caused by fertilisers and monocultures on ecosystems and local economies triggered the UN to be more critical about the long term effects of large scale technical projects common to processes of industrialisation (Lucena & Schneider, 2008). This brought widespread attention, probably for the first time, to questions of how best to sustain 'development'. Since then the social and environmental impact and appropriateness of development activities has garnered increased attention globally, both in the media and in academic literature, and anxieties reported by environmental scientists and ecologists have been recognized by policymakers and economists. These events ultimately sparked the impetus to conceptualize, operationalize, and identify indicators of 'sustainable development', in order to generate policies for implementing national, international, and global sustainable development agenda.

The most popular or influential definition of sustainable development is the one formulated by the World Commission on Environment and Development (WCED) in 1987. In the report '*Our Common Future'*, the WCED described sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987: 43). Although this formulation is often criticised for being too vague, in some ways it is useful in shaping our thinking about what we might want development to look like. Firstly, it adds a time dimension to conceptions of development, prompting us to question how long development can look the way it does, and still be considered as a manifestation of positive change in society. Secondly, as pointed out by Anand & Sen (1994) and Mebratu, (1998) there are two key concepts contained in this definition:

1. The concept of needs, especially the basic or essential needs of the world's poor, to which overriding priority should be given.
2. The concept of limitations, particularly the restrictions imposed on the natural environment's ability to absorb the effects of human activity, or renew its resources due to the state of technology and social organization (see WCED, 1987).

Thus conceived, we cannot take it for granted that development efforts have a positive effect on, or improve the lives of human beings, if they neglect the needs of the poor or limit opportunities for the environment to renew itself so that it might cater for the future needs of both human and non-human life. As such, anyone driven by either long-term self-interest, or concern for poverty, or concern for intergenerational equity would arguably be willing to support the operational objectives stemming from the WCED's definition of sustainable development (Mebratu, 1998). Such a broad definition of sustainable development lends itself to consensus because it is founded on scientific evidence on environmental degradation, moral and ethical principles about poverty, and considerations for long term self-interest (Repetto, 1986). Therefore, theoretically, this formulation of sustainable development has the potential for building a broad and powerful consensus (Mebratu, 1998). Indications of the resonance this definition has in shaping mainstream understandings of sustainability is reflected by its widespread use and frequency of citation (Robert et al., 2005).

The three dimensions that have come to be understood as the pillars of sustainable development are: the environment, the economy, and society (people). According to Robert et al. (2005), much of the early literature on sustainable development focused on the economic dimension, placing emphasis on the need to maintain productivity levels in industry and wealth in parts of the world where it had been achieved, or providing employment and increasing economic participation for the worlds' poor. Over time, the social dimension of sustainability has received increased attention, where there is more emphasis on values and goals such as increased life expectancy, education for all, and equity (Robert et al., 2005). Within the last five decades, a number of key international milestones[1] signified the increased recognition of sustainability as an important component in development strategies. These include the:

- 1972 UN Conference on the Human Environment;
- 1992 UN Conference on Environment and Development (UNCED) or 'Earth Summit' (where 'Agenda 21' was agreed upon as a blueprint for sustainable development, reflecting global consensus and political commitment to integrate environmental concerns into social and economic decision-making processes);
- 2000 UN Millennium Summit (where the Millennium Development Goals (MDGs) were adopted, which included eight anti-poverty targets to be accomplished by 2015);
- 2002 World Summit on Sustainable Development (WSSD) (where commitments to sustainable development were reaffirmed alongside a notion of development that aims for equity within and between generations, and poverty eradication placed at the centre of sustainability measures); and
- 2015 UN Sustainable Development Summit (where world leaders adopted the 2030 Agenda for Sustainable Development, which includes a set of 17 Sustainable Development Goals (SDGs) to end poverty, fight inequality and injustice, and tackle climate change by 2030.

(DEAT, 2008; UN, 1972, 2012; UNCED, 1992; UNDP, 2015; WSSD, 2002).

According to the UN's Global Sustainable Development Report, vast progress has been made on the MDGs, showing the value of a unifying agenda underpinned by goals and targets (UN DESA, 2015). While the MDGs aimed at an array of issues that included reducing poverty, hunger, disease and gender inequality by 2015, the new SDGs, and the broader sustainability

[1] See also Sustainable Development Timeline (IISD, 2012).

agenda seek to go further than the MDGs to address the root causes of poverty and the universal need for development that works for all people (UN DESA, 2015). Human development features quite strongly into this sustainable development landscape. The human development reports[2] (HDRs) emphasise that human development and sustainability are essential components of the same ethic: the universalism of life claims (UNDP, 2015). As argued in the latest report (see HDR 2015), the strongest argument for protecting the environment, from a human development perspective, is to guarantee future generations a diversity and richness of choices and substantive opportunities similar to those enjoyed by previous generations (UNDP, 2015).

1.2 Locating engineering in sustainable development

Engineering solutions have traditionally been seen as examples of development that works for all people by advancing human productivity and prosperity. This is because engineering activities usually result in the creation of social artefacts that have come to be recognised as manifestations of development, for example, infrastructure in the form of railways, roads, mechanised forms of transportation, electricity and so forth. It is therefore often taken for granted that the education and training received by engineers, subsequently enables them to respond appropriately to challenges of sustainable development through their contribution to the design and creation of innovative processes and products, e.g. creating biogas[3] from natural waste as a source of renewable energy. However, engineering education has traditionally emphasised mastering technical subject matter at the expense of promoting values that underpin sustainable development; hence, not all engineering contributes to sustainability. Moreover, some engineering products (e.g. luxury vehicles) perpetuate inequality by serving the needs of the wealthy and not those of poor and marginalised communities (to which overriding priority should be given).

To address this shortcoming of engineering, higher education institutions and universities in particular, are increasingly incorporating the humanities and sustainable development content in their engineering programmes (Ahern, O´Connor, McRuairc, McNamara, & O´Donnel, 2012; Boni & Berjano, 2009; Boni, McDonald, & Peris, 2012; Paden, 2007). Measures to

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[2] Human Development Reports are produced by the United Nations Development Programme (UNDP). The first report was published in 1990 (see UNDP, 1990) and subsequent issues seek to bring the human development perspective to bear on a range of contemporary societal issues (for example see UNDP, 2015).

[3] Biogas is a mixture of different gases produced by the anaerobic digestion of organic matter. It can be produced from raw materials such as agricultural waste, manure, municipal and food waste, plant material and sewage. For more information, see for example http://reenergise.co.za/industry/bioenergy/ .

incorporate sustainable development concerns in engineering curricula illustrate institutional responses to global action plans for sustainable development such as the DESD. These measures are justifiably often targeted at engineering education because engineers' work cuts across and influences, arguably more directly than any other professional group, the so-called pillars of sustainable development: people, the environment, and the economy.

ESD literature (see De La Harpe & Thomas, 2009; Fadeeva & Galkute, 2012; Grobbelaar, n.d.; Hopkins, 2012; Jones, Trier, & Richards, 2008; Karatzoglou, 2013; Lozano, 2013; Mulder & Jansen, 2006), suggests that relevant and appropriate knowledge for sustainable development can be imparted through adding humanities courses to university curricula. In particular, studies that focus on reforming engineering pedagogies to this end recommend approaches such as project-based learning[4], problem-based learning[5], back-casting[6] (see Connor et al., 2014; Fernandes et al., 2012; Fernandes, Mesquita, Flores, & Lima, 2014; Schneider, Leydens, & Lucena, 2008; Segalás, Ferrer-Balas, & Mulder, 2010) and the use of design studios (see Petersen, 2013) as methods to broaden outcomes. These studies suggest that such alternative approaches to engineering curricula and pedagogy expose students to both technical and qualitative aspects of engineering work, while developing their soft skills and making them knowledgeable about sustainability.

Although there is evidence of progress towards sustainable development practices in engineering, there are numerous examples of engineering outcomes that are unjust (consider the previous example of luxury cars that exclusively cater for the needs of the wealthy) and as stated in the 2015 HDR 'the indignity of poverty has not been ended for all' (UN DESA, 2015). Another issue of concern from a social justice point of view is that in most parts of the world, the conventional use of urban space is limited to the wealthiest citizens who reap the benefits of public investments in infrastructure, while the less privileged have restricted and problematic access to infrastructure (Lucena, 2013). Although it can be argued that all forms of development benefit all sectors of society through 'trickle down' effects of economic

[4] Project-based learning refers to teaching approaches that use multifaceted projects as a central organizing strategy for educating students. Students are typically assigned a project that requires them to use diverse skills (researching, writing, interviewing, collaborating etc.) to produce various work products (research papers, scientific studies etc.)

[5] Problem-based learning is a student centred pedagogy that entails group work to solve complex and real-life problems and helps develop students' content knowledge and their problem-solving, reasoning, communication, and self-assessment skills.

[6] Back-casting refers to developing normative scenarios and exploring their feasibility and implications. In ESD, it is as a tool with which to connect desirable long-term future scenarios to present situations by means of a participatory process.

activities, the urgency of poverty deserves attention and intervention that is much more direct. If this is not done, then humanity will remain at a defining moment in history, where we are still confronted with a perpetuation of disparities between and within nations, high levels poverty, and the continuing corrosion of the ecosystems on which we are all dependant for our well-being (UNCED, 1992). From a social justice point of view, one can neither speak of prosperity nor development, if infrastructure pioneered by engineers perpetuates social inequalities, causes irreversible environmental degradation or leads to the displacement of local communities (Cumming-Potvin & Currie, 2013). Such adverse consequences of development efforts indicate that progress is not necessarily linear, and they suggest that some social artefacts designed to promote progress and result in a better life for all, can reduce the quality of life (Ruprecht, 1997). Because engineers often work at the forefront of development projects, they need to be equipped with knowledge and values that can aid them to make appropriate judgments about technologies worth pursuing to achieve development objectives that are just.

It must be acknowledged that a wider group of professionals (e.g. quantity surveyors, architects, town planners, development aid workers and even contractors and financiers) have knowledge, skills, or resources that are applied in the conceptualisation and implementation of products and processes that characterise development. For example, town planners deal with technical and political processes concerned with the use of land, protection and use of the environment, public welfare, and the design of the urban environment, including air, water, and the infrastructure passing into and out of urban areas, such as transportation. Engineers often work with professional groups like town planners, and as a collective, the results of their work frequently positions them at the forefront of development initiatives. It is therefore clear that engineering work cannot be carried out without the input of such professional groups, and engineers have to work within the confines of government regulations or economic and environmental constraints. However, engineering knowledge, which is 'limitless it its scope and detail'(Trevelyan, 2014) sets engineers apart from their counterparts. They possess technical expertise that can be used to design, construct, and hence shape the world in which we live. It can therefore be argued that engineers are particularly well placed to help ensure that social artefacts like technology are placed at the service of sustainable development.

As Fernández-Baldor, Boni, Lillo, & Hueso (2014) assert, transferring the benefits of technology to society is not a straightforward task. Fernández-Baldor et al. (2014) argue that when development aid interventions strictly view technology as a necessary tool for development, attention lies in supplying technological assets or services, focusing only on technology, instead of concentrating on people. Such approaches to development and development aid projects diminish the potential for social transformation through engineering and technology (Fernández-Baldor et al., 2014). Fernández-Baldor et al. (2014) subsequently ask that we see technological development projects not only as a means to provide an asset or a service, but also as a tool for helping people to shape their own lives and for reducing inequalities. This view on technological development projects requires professional groups at the forefront of development efforts to embrace values associated with social justice. If such values do not underpin their professional functionings, they might fail to use their knowledge and skills to enhance human development or to solve sustainability problems in a just way. It is therefore important that appropriate conceptions of 'development' are held by professional groups who design, produce and implement technologies in society for the purpose of human progress. This is important, particularly for professional groups like engineers, because their understanding of development determines how they identify or recognise it, as well as how they measure it.

In the section that follows, I argue that the capability approach and human development paradigm offer appropriate views on development, and I explain why they serve as a powerful normative lens through which to conceptualise the ends of engineering education. Additionally, sustainable human development and 'public-good professionalism' (Walker & McLean 2013) are discussed as frameworks within which I begin to conceptualise 'public-good engineering'. By so doing, I explain how my thesis uses the capability approach both a lens for theorizing, and a site for analysing the contribution engineering education makes to sustainable human development.

1.3 Conceptual foundation for a normative account of engineering education

My thinking surrounding engineering education is grounded in the capability approach (Nussbaum, 2000; Sen, 1999) and the human development paradigm (ul Haq, 1995). Conceptions of sustainable human development (Anand & Sen, 1996; Costantini & Monni, 2005; Crabtree, 2013; Landorf, Doscher, & Rocco, 2008; Lessmann & Rauschmayer, 2013; Peeters, Dirix, & Sterckx, 2013; Pelenc, Lompo, Ballet, & Dubois, 2013), and public-good professionalism (Walker, 2012; Walker & McLean, 2013) also inform my reasoning. Because a more in-depth discussion of the capability approach and its application to higher education research follows in chapter 4, this section is limited to outlining the approach in order to situate the study theoretically. At the same time, the section discusses ideas and concepts that correlate with and inform the capability approach in order to accentuate the rationale of the study, and introduce its theoretical ambitions.

1.3.1 The capability approach

The capability approach (Sen, 1999; 2003) is a broad normative framework rooted in a philosophical tradition that values individual freedom, and is used for the evaluation and assessment of individual well-being, social arrangements and the design of policies and proposals about social change (Alkire, 2002). It provides an alternative view of development by conceptualising development as freedom (Sen, 1999); the core focus of the approach is on the effective freedom people have to be and to do what they have reason to value (Robeyns, 2005). In discussing the capability approach further, particular attention is focused on describing its key concepts: capabilities, functionings, agency, conversion factors, and well-being.

The starting point of the capability approach is Amartya Sen's argument that focusing on the expansion of human freedom as an end of education endeavours, instead of focusing on economic progress, allows economic growth to be integrated into an understanding of development processes as "the expansion of human capability to lead more worthwhile and more free lives" (Sen, 1992: 295). Based on this view, human freedoms or human 'capabilities' lie at the heart of development (Walker, 2006), where the term 'capabilities'[7] refers to substantive freedoms, or what is effectively possible. When that which is effectively possible has been attained or achieved, it is known as a 'functioning'. Functionings can therefore be described as the realised potential of capabilities, and they are characterised by 'beings' and 'doings' that are (usually) aligned with an individual's aspirations and/or well-being.

The capability approach draws attention to two distinguishable yet equally important and interdependent aspects of human life, namely well-being and agency (Sen, 1999). Well-being and agency play a pivotal role in shaping our understanding of how individuals and groups (see Ibrahim, 2006; Stewart, 2005) are functioning (Crocker & Robeyns, 2010). Agency is

[7] In this thesis, the term 'capabilities' or 'capability' is used to refer to effective freedoms, opportunities, possibilities and/or choices as defined in Sen's (1999) capability approach. It is therefore not to be confused with the general definition of capability as 'ability' or a measure of one's aptitude.

defined as the capacity to initiate an action through formulating aims and beliefs, and it requires mental health, cognitive skills and opportunities to engage in social participation (Alkire, 2002). Agency is also distinguished according to agency freedom and agency achievement. According to Sen (1985), agency freedom refers to the liberty an individual has to turn available opportunities into valued outcomes. That is, the freedom one has to bring about the achievements one values and tries to produce. Agency achievement refers to the realization of the goals one has reason to pursue (Sen, 1985). The concept of agency is more wide ranging than personal well-being and this distinction is important because it underscores that individual choice can be influenced by the social and relational environment in which one lives, which can result in decisions that are not particularly conducive to individual well-being (Sen, 1985).

Thus conceived, "there is deep complementarity between individual agency and social arrangements" and it is "important to give simultaneous recognition to the centrality of individual freedom and to the force of social influences on the extent and reach of individual freedom" (Sen, 1985: 206-207). This means that although individuals may be free and able to pursue valued objectives, social arrangements can have an effect on the resultant choice of action individuals may take. For example, budget constraints enforced on engineering projects by senior management in a construction firm may inhibit engineers' freedom and ability to design environmentally friendly products. This could lead to decisions that prioritize economic profit over sustainable engineering practices. This example represents a situation where, despite in theory having the freedom to decide otherwise, an individual may make a decision that is: a) not necessarily aligned with their intrinsic motivation b) may not reflect their aspirations and c) has the potential to diminish their professional well-being. Unfortunately, current global economic conditions are not conducive to these freedoms in the engineering industry. Traditional business models that emphasise maximising profit and minimising costs dominate industry, with the result that the economic dimension of sustainability is prioritised at the expense of the social and ecological dimensions.

Ideally, one's social environment should offer a space in which the freedom to strive towards intrinsically valued beings and doings is provided. For engineers specifically, their professional environment should offer a space in which they are free to strive towards advancing sustainable development and social justice. Correspondingly, engineering education should offer possibilities to develop graduates' capacities to value principles of social justice and sustainable development, so that they may have reason to value these ideals and hence work towards them through their professional functionings. That is, so that future engineers might become agents who act and make change happen (Sen, 1999), change that is dedicated to social justice. Thus conceived, and drawing on Alkire & Deneulin's (2010) characterisation of agency, agentic engineers can be described as individuals who seek to:

1. Pursue goals that they value, in particular, goals that are aligned with the principle of social justice, such as poverty reduction.

2. Apply their effective power, not only according to their individual agency but also according to what engineers can do as members of a group, for example as members of Engineers Without Borders, or as members of communities or political communities.
3. Pursue individual well-being or other reasonable and justifiable objectives that are conducive to societal well-being (displacing local communities for engineering endeavours cannot be understood as agency) and
4. Take ownership of their responsibility as agents who want to achieve those goals.

As mentioned before, the capability approach makes a distinction between well-being and agency freedoms, and well-being and agency achievements; where freedoms are concerned with the real opportunities one has to accomplish what one values, and achievements are concerned with what one actually manages to accomplish (Crocker & Robeyns, 2010).

The example that was provided previously (budget constraints imposed on engineering) illustrates a situation where limits to agency freedom get in the way of agency achievement.

As such, the capability approach proposes that the ends of well-being or development be conceptualised, amongst other things, in terms of people's *effective* opportunities to undertake the actions and activities they want to engage in, and to be whom they want to be or achieve desired goals (Crocker & Robeyns, 2010). In the case of engineers, we would therefore ask questions such as, 'What effective opportunities exist for engineers to design, create, and implement engineering solutions that serve sustainable development?'

In its account of human diversity in the evaluation of well-being, the capability approach acknowledges the role of contextual factors that influence how a person can be or, is free to convert the characteristics of goods or services into a functioning (Crocker & Robeyns, 2010). These elements are defined as 'conversion factors', which can take the form of personal (internal to the individual person), social (the society in which one lives), and environmental (emerging from the physical environment in which one lives) forces at work (Sen, 2003). Applied to engineering, budget constraints can be seen as social conversion factors that get in the way of engineers' freedom to convert engineering knowledge into sustainable engineering solutions.

As such, the capability approach can be described as a wide ranging normative framework which can narrowly be used to tell us what information we should look at if we are to judge how well someone's life is going or has gone, and can broadly be used as an evaluative framework within which to conceptualise, measure and evaluate well-being (Crocker & Robeyns, 2010). That is, the capability approach can be used to tell us what information we should look at if we are to judge how well engineering functionings are going or to evaluate and measure professional engineering capabilities. By so doing, it can help to conceptualise 'professional engineering well-being'. This can serve as a basis upon which to identify educational capabilities and functionings that are necessary to develop engineers who use their agency to secure their own well-being, while at the same time enhancing effective opportunities for all people (but particularly the poor).

However, there are some methodological challenges of the capability approach in this regard. It has been criticised for its failure to identify empirically verifiable categories of capabilities and functionings, which makes it difficult to operationalize empirically (Walby, 2011). Walby (2011) addresses the relationship between Sen's theoretical work and its interpretation in the measurement of justice, where the central question asked is whether it is possible to develop a meaningful operationalization of Sen's philosophical distinctions between capabilities and functionings. Walby (2011) identifies a few problems with Sen's preference for capabilities (opportunities) rather than functionings (achievements) as the basis of justice. These challenges are:

- Identifying the most important capabilities;
- Mapping the philosophical difference between capabilities and functionings onto a distinction between empirical categories; and
- Evaluating potentially incommensurable categories.

Another possible limitation of the approach is that it does not provide an actual formula for interpersonal comparisons of well-being, nor does it offer sufficient guidelines for its operationalization or clear methods of identifying valuable capabilities (Crocker & Robeyns, 2010). However, it is important to note that attempts have been made to do so, as exemplified by the Human Development Index (HDI)[8] and the Multidimensional Poverty Index. Furthermore, Sen's ideas constitute the core normative principles of a development approach that has evolved in the HDRs, because they offer a favourable alternative view on human development. This view is not limited to seeing only resources and income as indicators of development (Walby, 2011). Therefore, the capability approach (despite these limitations) provides a good starting point for a more holistic examination and understanding of the purposes of engineering education, because it encourages us to consider individual opportunities for well-being achievement in higher education. It therefore, also prompts us to consider how the effective individual capabilities of professional agents contribute to the well-being of others and to societal well-being. This is because it defines development as pertaining to positive processes of social, economic and political change that broaden valued capabilities (Alkire, 2002; Sen, 2003). This means that it does not view the purpose of higher education as solely a means for individuals to achieve economic gains through employment. Instead, it inspires us to ask how individual capabilities (and functionings) and wider societal well-being are being broadened because of higher education. The capability approach is therefore well suited for use as a framework under which the value of higher education (and engineering education more specifically) can be examined beyond its economic utility.

If one primarily defines well-being according to its economic dimension, it is easy (and appropriate) to evaluate the work engineers do as a contribution to (economic) development. This is because transforming natural resources into means of production for industrialization and expanding infrastructure or advancing technology, are all examples of engineering outcomes that are indispensable to economic development. For these reasons, it is often taken for granted that engineering outcomes contribute to development and ultimately improve human well-being. If one looks at well-being from a capabilities perspective, engineers' contribution to development would be evaluated differently; according to the freedoms all people have to live lives that they consider valuable.

According to Fukuda-Parr (2003), this evaluative account of development and well-being provided the robust conceptual foundation for Mahbub ul Haq's human development paradigm (ul Haq, 1995). The next section shows how the capability approach and human development paradigm interrelate and inform each other to form the basis of my normative

[8] The HDI is a composite measurement of life expectancy, education, and income per capita indicators, which are used to rank countries into four tiers of human development thereby assessing human wellbeing from a broad perspective that goes beyond income (UNDP, 2015).

account of engineering education. Moreover, by locating capabilities and agency firmly in the human development paradigm, this reduces the risk of the capability approach being domesticated, especially by researchers who are not properly familiar with the full range of its concepts and philosophy.

1.3.2 Human development: the overarching goal

The human development paradigm is founded on the idea that the purpose of development is to improve human lives by expanding the range of people's capabilities and functionings. Therefore, the capability approach conceptualises development as freedom to be and do what one has reason to value, while the human development paradigm conceptualises the purpose of development according to the expansion of the range of those freedoms, with particular attention to the lives of the vulnerable and poor. Examples of general human capabilities and functionings include being healthy and well nourished, being knowledgeable or being able to participate in community life (Nussbaum, 2000). According to Anand & Sen (1994), human development, in the form of people being better educated, more healthy or less debilitated etc. is not only constitutive of a better quality of life, but it also contributes to one's productivity and ability to make a larger contribution to human progress and material prosperity. However, we need to avoid seeing human beings as merely the means of production and material prosperity, because that is the danger to which an approach that sees people as 'human capital' is open (Anand & Sen, 1996).

Rejecting an exclusive concentration on people as human capital is central to the human development paradigm. However, it does not deny the commanding role of human capital, human resources, or a human work force in enhancing production and substantial wealth. There is no denial that the quality of human life can further be increased by material prosperity that is advanced by human development (Anand & Sen, 1994). Nevertheless, from a human development perspective, development is ultimately about removing the obstacles or challenges that limit the range of things a person can do or be in life. Examples of obstacles include illiteracy, ill health, lack of access to resources, or lack of civil, political, or economic freedom (Fukuda-Parr, 2003). In engineering education, an example of an obstacle to a wide set of professional capabilities is educating engineers for the sole purpose of employment. If engineering education focuses too heavily on technical employability skills and neglects cultivating their humanity, it becomes an obstacle to engineering graduates' potential functionings both within the workplace and outside of it.

Too heavy an emphasis on technical expertise, to the exclusion of developing transversal skills like critical thinking, diminishes engineers' professional capabilities. Narrowing engineering education outcomes to technical knowledge limits students' opportunities to establish, show, and improve their knowledge of and commitment to sustainability challenges. This gets in the way of achieving social justice because it limits engineering students' effective freedom to channel their skills and knowledge explicitly towards solving problems such as extreme poverty.

As ul Haq (1995) states, treating human beings as only a resource for the production process clouds the centrality of people as the ultimate end of development. As such, human development is concerned both with building human capabilities through investment in education and health and with using those capabilities fully through an enabling framework for growth and employment (ul Haq, 1995). This means that the human development model regards economic growth as being of vital importance, but it pays equal attention to its quality and distribution, its link to human lives and to its sustainability (ul Haq, 1995). The difference between economic growth or utilitarian models of development and the human development model is that the former prioritise the expansion of income and its uses, while the latter embraces the enlargement of *all* human choices; ranging from economic and political, to social and cultural (ul Haq, 1995). As Boni & Walker (2013) posit, a human development perspective, with its core values of well-being, participation, empowerment, and sustainability could be a good framework within which to rethink and reimagine a different vision of the university. This is because a human development framework advances the notion that, while education can enhance human capital, people also benefit from education in ways that exceed its role in commodity production (Boni & Walker, 2013). That is, human development highlights both the instrumental and intrinsic values of education and higher education.

To summarise, the human development model questions the presumed (automatic) positive relation between expanding income or economies and expanding human freedoms. It reminds us that there is more to the well-being experienced by human beings than their personal economic positions, or their economic contributions to society. For these reasons, it serves well to aid my exploration of broader values associated with university learning, as it encourages investigating what graduates gain from higher education, beyond skills for employability. If engineering education is to contribute to engineers' human development it should produce engineering graduates who can in turn contribute to the human development of others in their personal and professional capacities. That is, engineering education should enhance graduates' personal and professional capabilities, so that they might in turn enhance the capabilities of others through their citizenship and employment.

Questions about education and its contribution to human development cannot be addressed without making considerations about ways to sustain desirable levels of human development that we do or might reach. The discussion in the next section considers the conceptual contribution sustainable development makes to the capability approach and human development paradigm.

1.3.3 Sustainable human development

The capability approach, while conceptually rich in its normative account of development, says little about how to maintain or sustain the freedoms that we might achieve for people. This point is made strongly by Wolff & De-Shalit (2007) in their emphasis on secure functionings. It is important to note that Sen's (1999) capability approach acknowledges human diversity to the point that it does not prescribe a fixed set of beings and doings that individuals should strive for to achieve well-being. Instead, it identifies freedom as the most indispensable condition to achieving well-being. This makes it difficult for the capability approach to describe, specifically, what the future should be like for people; it places that responsibility in the hands of people themselves to define this through processes of public deliberation (Sen, 2003). In other words, the approach does not predefine what people will value being and doing in the future.

The ontological basis of the capability approach encourages the assumption that effective *freedoms* to choose and pursue valued beings and doings will always matter to all people. For this reason, Sen (1999) argues for the importance of public participation, dialogue and deliberation in arriving at valued capabilities for specific situations and contexts. He argues that all members of any collective or society "should be able to be active in the decisions regarding what to preserve and what to let go" (1999: 242). The process of public discussion should enable individuals to be active contributors to change; citizens whose voices count (Walker, 2006). Sen (1999) is thus critical of the idea that 'pure theory' can substitute for the reach of democracy, or that a list of capabilities (or SDGs and MDGs) can be produced irrespective of what the public understands and values.

On the contrary, Nussbaum (2000) is a proponent of a universal, cross-cultural list of central capabilities and she argues that we need to have some idea of the kind of freedoms we are striving towards, and agree on them. Nussbaum (2000) therefore gives specific content to capabilities, disagreeing with Sen's reluctance to make commitments about what capabilities a society should primarily pursue. The lack of commitment to specific valued capabilities means limited guidance in thinking about social justice (Nussbaum, 2000). Nussbaum's tentative and revisable list of ten central human capabilities are: 1) Life; 2) Bodily health; 3) Bodily integrity; 4) Sense, imagination, and thought; 5) Emotions; 6) Practical reason; 7) Affiliation; 8) Other species (viz. living with a concern for); 9) Play; and (10) Control over one's political and material environment (Nussbaum, 2000: 78). Nussbaum (2000) asserts that these capabilities are the core requirements for a decent life and that they represent a minimal agreement on social justice. Furthermore, a society that does not guarantee the active cultivation and stimulation of such key freedoms cannot be considered a just society, whatever its level of affluence (Nussbaum, 2000). Therefore, while Sen's capability approach does not suggest what people will value being and doing in the future (aside from being free to do and to be what they deem valuable), Nussbaum's capability list provides a starting point for deliberating about general capabilities worth pursuing and hence worth sustaining. Furthermore, capabilities 8) and 10) on Nussbaum's list (the capability to live with concern for other species and the capability to have control over one's environment) are clearly relevant for considerations of the relationship between human beings and non-human life, which is an important element of sustainable development and hence important for our thinking about sustainable human development.

As Anand and Sen (1994) point out, there is no basic difficulty in broadening the concept of human development as outlined in the HDRs, to accommodate claims of future generations and the urgency of environmental protection, as done in the WCED's definition of sustainable development. Anand and Sen (1994) suggest that the human development paradigm translates readily into a critical and overdue recognition of the need for active international efforts to preserve the quality of the environment in which we live. That is, we can evaluate how the human developments we have achieved in the past, and what we are trying to achieve at present, can be sustained in the future (and further extended) rather than being threatened by cumulative pollution, exhaustion of natural resources, and other deteriorations of global and local environments (Anand & Sen, 1996). At the same time however, safeguarding future capabilities has to be done in a way that does not compromise current efforts towards the elimination of widespread deprivation of basic human capabilities, which characterize the unequal and unjust world in which we live (Anand & Sen, 1996).

While it is clear that the WCED's definition of sustainable development does not unpack the notion of development per se, it does focus attention on questions surrounding the temporal dimensions of development and how desirable living conditions that have been achieved can and should be maintained. This temporal focus, which brings our attention to what ought to happen now as well as in the future, enriches the capability approach because it prompts considerations about the future in a way that the capability approach has not done exhaustively in its normative conceptualisation of development. That is, by not clarifying which capabilities will matter to this end in the future. Additionally, the capability approach is weaker on its emphasis of the importance of non-human life, specifically in relation to human beings relationship with the natural environment. By 'natural environment', I refer to all vegetation, microbes, soil, rocks, atmosphere, and natural phenomena that occur within their boundaries. Also included under the term natural environment are all universal natural resources and physical phenomena that lack clear-cut boundaries, such as air, water, energy, radiation, electric charge and magnetism, not originating from human activity.

A concern for the broader natural environment is implied in Nussbaum's (2006) concern with animals, many of which depend on a delicate interaction with the natural environment to survive. Nussbaum (2006) emphasises that human beings share the world and its scarce resources with other intelligent creatures that inspire sympathy and moral concern, and deserve a dignified existence. However, the focus of her argument about the importance of non-human life is not necessarily on the well-being of the natural environment itself. Nussbaum (2006) states that when we think about the concept of global justice, we typically think of extending our theories of justice geographically (to include more of the human beings on the Earth's surface) or temporally (to take account of the interests of future people). What comes to mind less often, Nussbaum argues, is the need to extend our theories of justice outside the realm of the human, to address issues of justice involving non-human *animals* (Nussbaum, 2006).

From her discussion of 'species membership' (see Nussbaum, 2006: 21-22) it is clear that Nussbaum's primary concern is about the lack of consideration for non-human life, particularly non-human animals, in our conceptions of social justice. That is, Nussbaum does not explicitly argue for the need to extend theories of justice to include the physical natural environment. In contrast, the theory of justice brought forward through the WCED's concept of sustainable development is specifically concerned with human beings' relationship with the physical environment, and it is much more prescriptive about what this relationship should look like in the future. As affirmed by Pelenc et al. (2013) the capability approach is much less explicit about ecological constraints (on human flourishing). It does not adequately emphasise the fundamentality of environmental sustainability or opportunities for the natural environment to thrive, as a prerequisite for human development.

Pelenc et al. (2013) argue that the current conceptualization of the capability approach makes it a difficult instrument to assess the sustainability of human well-being. This weakness can be overcome by a stronger acknowledgement of the intrinsic and instrumental values of nature, thereby adding an ecological or environmental dimension to the approach (Pelenc et al., 2013). Another recommendation made by Pelenc et al. (2013) is that the ex-ante dimension of responsibility should be integrated into the capability approach, as opposed to considering responsibility from a consequentialist viewpoint (i.e. ex-post responsibility). That is, instead of viewing responsibility as something that emerges once a person exercises their freedom to act; it should be seen as existing even prior to taking action. For example, engineers do not become responsible for the environment because of their past actions (e.g. helping to create nuclear energy); they are responsible for the environment by virtue of possessing capacities for moral judgement, in the form of knowledge, skills, and effective power and freedom to do so. By fully integrating the ecological dimension of well-being into an extended vision of the capability approach, a new definition of an agentic engineer arises: a responsible individual acting so as to "generate sustainable human development for future persons" (Pelenc et al., 2013: 77).

Pelenc et al. (2013) also argue that descriptions about the relationship between the individual and collective experiences of well-being achievement should be strengthened by the idea of 'collective agency'. Scholars of the capability approach have sought to define collective capabilities (or group capabilities) and collective agency in several ways. While Stewart (2005) defines collective capabilities as the average of all selected individuals in a group; Comim and Kuklys (2002) view collective capabilities as more than the aggregation of individual capabilities. Instead, collective capabilities are described as the freedoms that can only be achieved because of social interaction (Comim & Kuklys, 2002). In this view, individual capabilities are governed by collective capabilities, because the act of choosing the life that one has reason to value might be a collective rather than an individual act (Ibrahim, 2006).

Sen (2002) on the other hand, rejects the concept of 'collective capabilities'. He argues that capabilities resulting from collective action still remain 'socially dependent individual capabilities' (Ibrahim, 2006). For Sen, only those capabilities related to humanity at large, such as drastic reductions in poverty, can be considered collective capabilities (Ibrahim, 2006; Sen, 2002). In emphasizing the importance of collective capabilities, it is necessary to introduce the concept of collective agency. Collective or group freedom is the freedom of a group of individual agents to perform a set of distinct actions in combination; they constitute the new range of choices that individuals (as a group) gain as a result of collective action (Ibrahim, 2006).

In order to expand their collective freedoms and capabilities, individuals need to exercise agency. Acts of agency are mainly affected by prevailing communal values and social structures; therefore, agents are constituted by and constitute structures (Ibrahim, 2006). That is, individual agency brings about change not only through individual deeds, but through formal and informal collective action (Deneulin & Stewart, 2002). In contrast to individual agency where a person 'individually' pursues their own perception of the good, through acts of collective agency, the individual can pursue this perception of the good collectively by joining or participating in a group with similar goals (Ibrahim, 2006). For example, individual engineers seeking to enhance human development for poor communities can join groups such as Engineers Without Borders.

Collective agency is thus not only instrumentally valuable for generating new capabilities, but also intrinsically important in shaping and pursuing the individual's perception of the good (Ibrahim, 2006). As Ibrahim (2006) asserts, it is indisputable that human beings can bring about changes in their societies both through individual and collective actions. The important question is, which way is more effective? (Ibrahim, 2006). Ibrahim (2006) agrees with Fukuda-Parr (2003) that collective action is a vital force that can pressure changes in policies and bring about political change. Collective agency is therefore crucial for people to influence the social structures in which they live (Ibrahim, 2006). In the case of engineers, collective agency is crucial for them to be able to influence engineering work structures or pressure changes in industry so that poverty reduction might feature more strongly in companies' policy imperatives.

As mentioned earlier, engineering activities are central to the creation of social artefacts and systems (roads, railways, wastewater systems etc.) that have generally been seen as manifestations of development. This is because such artefacts represent the transformation of natural resources into infrastructure, which serves universal human needs and the global economy. Considering that engineers are major contributors and often pioneers of technological advancements which are created to contribute to development, they have to make moral judgments about technologies, products and processes that are worth pursuing to achieve sustainability. Through the lens of the capability approach and human development paradigm, if engineering outcomes do not increase possibilities for current and future generations globally to live the kind of lives they have reason to value or achieve valued functionings, then they are not necessarily examples of sustainable development. To summarise:

> [S]ustainability is a matter of *distributional equity* in a very broad sense, that is, of sharing the capacity for wellbeing between present people and future people in an acceptable way- that is in a way which neither the present generation nor the future generations can readily *reject* (Anand & Sen, 2000: 2038).

If we think about sustainable development from a capabilities perspective, the main implication for engineering education is that it should provide students with opportunities to develop, demonstrate and deepen their commitment to enhancing the capabilities of the poor, and the capacity of the environment.

While one can argue that many students in engineering programmes have chances to learn about ways in which they can contribute to reducing carbon dioxide emissions through their work, thereby redressing environmental pollution, it is more difficult to claim that the same students have chances to meaningfully learn how they might, redress extreme poverty through their work. As the review of literature (chapter 3) will show, there are many examples of curriculum reform in engineering education across the world, which reflects institutional responses to global action plans aligned with ESD. Unfortunately, most courses that teach 'sustainable development' generally interpret the purpose of ESD narrowly, primarily seeing ESD as a vehicle to teach students about environmental sustainability (Karatzoglou, 2013). This is unfortunate because, as mentioned earlier, the two key concepts of sustainable development are human needs, particularly those of the poor to which overriding priority should be given; *and* limitations of the environment to cater for current and future human and non-human life. These key concepts suggest that restoring environmental balance and eliminating poverty are *both* among the bottom line objectives of sustainable development. Moreover, eliminating poverty can also be considered as the bottom line objectives of the SDGs and MDGs. Eliminating poverty is therefore a cause that deserves much more attention in engineering programmes, and courses that address sustainable development. If sustainable development is to become the leitmotiv of engineering education, it can be argued that the primary concern of sustainability courses should be addressing questions related to how engineers can and should direct their knowledge, expertise, and effective power towards conserving the environment *and* eliminating poverty.

Looked at from a capabilities perspective, if development is characterised by enhanced capabilities and functionings, and the outcome of engineering activities is development, then we could argue that the main objective of engineering should be to create opportunities for people living in poverty or leading vulnerable lives to do and be what they have reason to value. In both cases, the implication is that engineering graduates ought to have opportunities to develop concern for, and commit to, alleviating poverty through their professional functionings. Failure to create these opportunities in engineering curricula and pedagogy, is problematic for public-good professionalism (Walker, 2012; Walker & McLean, 2013).

1.3.4 Public-good professionalism

Walker and McLean (2013) propose a view of professionalism grounded in the view that university-based professional education (of nurses, doctors, lawyers, engineers, teachers, social workers, economists and so on) ought to contribute to our opportunities to choose and to live in ways we find meaningful, productive and rewarding both individually and collectively to the good of society. The position advanced by Walker (2012) is that capabilities and functionings should not be left entirely unspecified for comparative assessments of justice. Rather, they should point to what it is that people (professional engineers in this case) ought to try to become for their own good lives and for the lives of others to flourish (Walker, 2012). As Walker (2012) argues, in order for us to adjudicate or evaluate what forms of professional practice are right and good, some professional and social ideal towards which we aspire ought to be identified. To develop through education our power, is then also to have a view on which powers are worth developing, and which ones not (Walker, 2012). Similarly, to develop through engineering education, graduates' skills, knowledge and effective power is then also to have a view on which professional capabilities and functionings are worth cultivating, and which ones not. More importantly, this judgement should be made with a particular focus on sustainable human development. That is, the capacities worth developing through engineering education have to be assessed according to their relevance for public-good professionalism or engineering which is *for* sustainable human development.

Sen (2009) emphasizes that as a key feature of justice, we need to recognise that capability is effective power. Thus conceived, if someone has the effective power to make a change that will reduce injustice in the world, there is a strong social argument for doing just that (Sen, 2009; also see Walker & McLean, 2013). Furthermore, research on social change suggests that if (professional) elites are sufficiently socially aware, they can play a significant role in transformative development, not only through quality in public services, but also by broadening civic participation and consolidating democratic reforms (De Swaan et al. 2000 as cited in Walker, 2012: 823). Thus, central to Walker and Mclean's (2013) account of professional capabilities, is the assumption that professional education has the potential to form agents who understand and respond to the plights of others and who have acquired through their university education the competencies, knowledge and values to contribute to human development. In this context, if university graduates have effective power to contribute positively to society, then they are obligated to do so. In the specific context of engineering, it can be argued that engineering graduates ought to use their talents as a common asset to benefit society, and in particular the least fortunate.

As Walker and McLean (2013) point out, we need to revisit the idea of what we mean by 'public services' in order to revive the understanding that a service is 'public', not because it is publicly funded, but rather when it is seen to serve the public. That is, citizens with legitimate claims on state resources that can expand their capabilities (i.e. opportunities for legal aid, health care, social welfare, urban infrastructure, clean water, and so forth). Therefore, the burden and challenges of social transformation should not fall entirely on professionals in the public sector, leaving those in the private sector free of obligations for positive change. This is of particular importance within the realm of professional engineering, where many qualified engineers opt to work in the private sector. In addition, both Sen and Nussbaum's conceptualisations of the capability approach are specifically concerned with the poor, vulnerable and disadvantaged. As such, capabilities-based professionalism requires professionals to attend to these lives, whatever else they might choose to do and be as professionals (Walker & McLean, 2013). Walker and McLean (2013) emphasise that a version of professionalism that inflects towards justice, empowerment, and capability enhancement aligns with the perspective that service should be judged and balanced against a larger public good. This implies that practitioners have a duty to judge what they do in light of that larger good, and to do so not as passive servants but active agents (Walker & McLean, 2013). Building on this line of argument, professionals ought to be educated in the direction of holding public-good values and committing to helping underprivileged communities. This is important for any unequal society, but most especially for developing countries like South Africa where there is a massive gap between rich and poor. Similarly, it is important for any profession, but most especially for (engineering) professionals whose work entails using technical knowledge and skills to convert natural resources into artefacts that can promote human well-being.

As Walker and McLean (2013) explain, capability-based professional ethics and practical engagement to bring about social changes requires the translation of normative ideas about justice into strategies and targeted interventions. This would constitute strategic interventions to embed higher, university and engineering education in particular, within a framework of social justice. Doing so would allow universities to take their place as institutions that cultivate 'engineers for social justice'. Therefore, a key criterion for quality in engineering education in universities ought to be how professional engineers are educated to use their knowledge and skills to enlarge the range of capability sets valued by poor and marginalised communities. Another important criterion would be how engineers can be educated to contribute to public policies and actions that enhance valuable functionings that are essential for freedom.

Drawing from this discussion of the concepts that shape my understanding of development and its sustainability, in this thesis I defend the claim that engineering education should be *for* sustainable human development. That is, engineering education should:

> Enlarge the professional capabilities and functionings of engineering graduates, provide them with meaningful opportunities to develop, demonstrate, and deepen their commitment to the cause of poverty eradication, and enhance their ability to exercise agency to promote sustainable human development as a public good.

Such a model of engineering education has the potential to nurture engineering professionals who contribute to reducing injustice through their actions. Furthermore, if engineers are educated with the knowledge and skills that enable them to function as agents of justice, they have the obligation to do so. However, how can engineers be educated to work for sustainable human development? At the same time, how can we enable engineers to make appropriate judgments concerning innovations and technological advancements worth pursuing to achieve sustainable human development? Thinking about these kinds of questions informed the aim and objectives of this study, which are described in the next section.

1.4 Aim of the study and research questions

Using the capability approach as a normative framework to define higher education's contribution to human development; this study seeks to explore, describe and combine German and South African perspectives on engineering education in universities and its contribution to sustainable human development.

The research questions that stem from this aim and guide this study are:

1. How can the capability approach offer a normative critique of engineering education in universities?
2. What capabilities and functionings are enlarged through engineering education? In addition, what implications do they have for pro-poor, public-good engineering?
3. How can engineering education enable graduates, through their work, to function as agents of sustainable human development?
4. How can engineering education also improve graduates' capability for employment?

1.5 Motivation to study German and South African perspectives

It is clear that the research questions cannot be adequately addressed without combining multi-dimensional views of engineering educators, practising engineers, engineering employers and engineering students from diverse contexts.

Whilst reviewing literature in order to inform my decision about the perspectives that my study would comprise of, I realised that much of what is written about higher education and engineering education in particular stems from data gathered in the global North, often written from global North perspectives. Comparatively few studies focus on normative accounts of education for sustainable development based on data from developing countries, and written from global South perspectives. This thesis, instead of dichotomising global

North/South perspectives, combines the views of individuals whose teaching and learning, higher education and/or professional careers in engineering have taken place in these regions. As such, the intention was to explore the perspectives of people whose experience and understanding of engineering education and engineering practice took place in a 'developed' country and merge these perspectives with those of people from a 'developing' country. This was done in an attempt to offer a richer, more nuanced and balanced account of engineering education; an account of engineering education which is theory driven in its normative stance yet data rich in its empiricism, and wide ranging in its perspective.

Germany and South Africa were chosen as examples of countries that represent the global North and global South, respectively. This decision was primarily pragmatic, but there are several reasons why the two countries specifically, make particularly interesting case study contexts for examining perspectives on engineering education. The pragmatic value behind the selection of South Africa lies in the fact that temporal and financial constraints place limitations on the scope of qualitative research that requires participants from distant countries. I am South African and conducting research in my home country was far more feasible and therefore made more sense than selecting another global South representative country. Germany was also a practical option because I lived and studied in Germany from 2009 to 2013. During this time, I established a strong network with diverse groups of people in Germany, became fluent in German and gained first-hand experience of life in a developed country. My familiarity with life and higher education in Germany and South Africa also placed me in a unique position from which to understand German and South African perspectives on engineering education. These considerations highlighted the fact that it would be significantly easier for me to recruit participants from Germany and South Africa as examples of global North and global South countries, rather than countries with which I have limited working knowledge.

Reasons why Germany and South Africa make particularly interesting case study contexts for exploring perspectives on engineering education lie in the stark differences and delicate similarities between the two countries. For example, Germany and South Africa are both economically dominant and energy intensive industrial powerhouses in their respective continents (Tyler, 2012). However, Germany is a wealthy developed country ranking 6th on the UN's HDI[9], whilst South Africa is a medium income developing country, with high levels of poverty and inequality and it is ranked 116th.

As Campt (2005: 1) asks, with regard to context, "How and why do we situate the stories we want to tell in the ways we do? What information needs to be known so that our stories make sense? Against what backgrounds and in what frameworks do we want our stories to be understood? What other stories do our tales cite or reference, and what differentiates our stories from those of others?". In agreement with Campt (2005), contexts (both discursive and socio-historical) are the possibility of existence and intelligibility of people's perspectives. Context also creates the boundaries of looking at, and understanding perspectives (Campt, 2005). In this thesis, describing the socio-historical context of higher education in Germany and South Africa is to delineate the space in which engineering education in universities can be understood. In particular, a look at the relationship between universities and social transformation within the two nations provides a rich backdrop upon which the relationship between engineering education in universities and sustainable human development can be elaborated on.

Starting with a discussion on the transformation of higher education landscapes in post-Apartheid South Africa and post-Nazi Germany, the next chapter (chapter 2) seeks to describe Germany and South Africa as societies, with a particular focus on the similarities, differences, and challenges that characterise universities. This is done in order to explore the significance of the context in which engineering education takes place, and to consider what this might mean for its contribution to sustainable human development. In addition, knowing more about the contexts where the research participants come from can enrich our understanding of their perspectives and experiences.

1.6 Thesis outline

This thesis is divided into two major parts. Part I looks at the context, background and theoretical basis of the study. It also attends to the literature review, conceptual framework, research questions, and methodology (chapters 1 to 5). Part II delivers the empirical results of the study, reflects on the conclusions drawn from them, and discusses the implications of the findings (chapters 6 to 10). The work of the respective chapters from here on out is summarised below, in chronological order:

[9] To see the latest HDI rankings visit: http://hdr.undp.org/en/countries .

Chapter 2: Student activism as catalysts of social change in Germany and South Africa

Chapter 2 shows that while there is value in considering German and South African perspectives on engineering education separately, what is original and significant about the work of thesis is the examination of these perspectives together, recognising that they are different views of the same issue: how engineering education in universities contributes distinctly to sustainable human development.

Chapter 3: Review of literature

In this chapter, a review of literature on engineering education is presented. It begins with a brief history of engineering and engineering education before discussing engineering graduate attributes and examples of incorporating the humanities into engineering curricula as a means to broaden engineering education outcomes. Thereafter, the discussion turns to non-technical i.e. 'soft' and transversal skills as intended outcomes of these efforts and attention is focused on how universities are reorienting engineering curricula and pedagogies towards sustainable development. Towards the end of the chapter, gender issues are considered before exploring the relationship between engineering and social justice. Through this review of literature, the contribution this thesis makes in the existing work on engineering education research is also highlighted.

Chapter 4: The capability approach and higher education research

Studies that examine higher education phenomena through the lens of the capability approach are discussed in this chapter. By so doing, the chapter revisits the capability approach in order to display its theoretical richness and strength, and demonstrate in more detail how it functions to help conceptualize the changes that need to take place within higher education globally if it is to contribute to social justice. Four dimensions of education that are important for public-good engineering are also discussed from a capabilities perspective. Attention is also given to turned to the methodology behind generating lists of educational capabilities, and drawing from this, a capabilities-inspired ideal-theoretical framework for public-good engineering (or engineering for sustainable human development) is proposed.

Chapter 5: Methodology

This chapter outlines the rationale behind the research process and addresses how I have gone about gathering the data that was used to answer the research questions. The chapter begins by discussing the research paradigm that frames the methodology. That is, a discussion of the relationship between the underlying epistemology, theory, research questions and adopted methods. Thereafter the research design, case study selection and participant recruitment process is described. This is followed by detailing the data collection methods and analysis procedure. A discussion of ethical clearance issues precedes the summative discussion that draws the chapter (and Part 1 of this thesis) to an end.

Chapter 6: Employers' views on education for public-good engineering

Addressed in this chapter, are perspectives from industry. The qualities of an ideal engineer, valuable non-technical skills, and employers' recommendations for universities are discussed here. The chapter also pays special attention to the views of the women employers to highlight their nuanced perspectives of engineering graduates' strengths and challenges. To conclude, a discussion on the emergent dimensions of public-good engineering is presented.

Chapter 7: Lecturers' perspectives on teaching and on engineering education

Chapter 7 discusses the value and purpose of engineering education and unpacks the different types of knowledge or ways of knowing that are considered as indispensable for public-good engineering. Thereafter findings are presented on what the lecturers thought they could do to teach transversal skills. As such, the chapter considers the findings presented in chapter 6, reflecting on the links that can be made between the empirical data across both chapters. Topics covered include, the purposes of engineering education, developing engineering identities, lecturers' valued functionings.

Chapter 8: Students' aspirations, valued capabilities and functionings

Engineering students' aspirations, valued capabilities, and functionings are presented here. An interesting interplay between these dimensions of individual well-being is revealed through understanding the motivations behind students' decisions to pursue careers in engineering. Students' views on their perceived roles in society as future engineers are also discussed and the chapter illustrates that is vital to ask questions about students' educational capabilities (instead of simply looking at their functionings), if one seeks to understand how university education enables them to thrive.

Chapter 9: The reach of engineering education in teaching sustainable human development

The penultimate chapter focuses on the reach of engineering curricula and pedagogies in teaching students values associated with sustainable development. It discusses how and what students learn about sustainable development, and their understanding of it. The chapter also describes the challenges of teaching sustainable development and reports on students' perceptions of their abilities to work as agents of sustainability. Drawing from the results of the previous chapters (chapters 6, 7 and 8) the relationship between the goals of engineering education, students' capabilties and functionings, and the dimensions of public-good engineering are theorised. By so doing, a capabilities-inspired, empirically informed framework for public-good engineering is presented. That is, the chapter concludes with a description of what engineering education for sustainable human development (EESHD) looks like.

Chapter 10: Summary, reflection and conclusions

The final chapter draws conclusions from, and reflects on the process that informed and shaped this thesis. It strings together the essence of the conclusions drawn from the various chapters that make up the study, paying special attention to how the research questions were answered. The theoretical contributions of the thesis are also summed up, and the main implications and limitations of the study are discussed. In addition, directions for future research are proposed and a short reflection on public engagement is presented, before I offer some concluding remarks.

1.7 Conclusion

The opening chapter of this thesis provided the background of the study through its discussion of development, sustainable development, and engineering education's location within this landscape. Through outlining the conceptual premise that informs the rationale behind this thesis, the chapter also explained why engineers (more than other professional groups at the forefront of development projects) have a moral, ex-ante responsibility to design, create and position social artefacts at the service of sustainable human development, in order to form societies that are more just. After describing the aim of the study and research questions, the motivation for considering German and South African perspectives was outlined. This motivation is significantly expanded on in the next chapter.

Chapter 2

Student activism as catalysts of social change in Germany and South Africa

2.1 Background

During the late 1940s, under Apartheid, the state was re-designed to organize civil society more firmly along the lines of 'race' and ethnicity in South Africa (Reddy, 2004). This translated into an administrative practice where all social services were provided separately and unequally (Reddy, 2004). The program of racially determining social relations allowed the state to centralize, administer and uniformly impose its ideology on educational policy in line with its Apartheid project (Reddy, 2004). By so doing, the National Party government introduced an interventionist character into relations between state and civil society, as it relates to the terrain of higher education (Reddy, 2004).

The ideological functions of educational policy under Apartheid were to socially stratify and segregate South African society even further. Therefore, educational resources were unequally distributed on the basis of race, resulting in a differentiated higher education landscape (Reddy, 2004). As a result, a particular higher education system was inherited from apartheid: one that was internally divided, and isolated from the international community of scholars (CHE, 2004). It was highly fragmented in structural and governance terms, and was far from being a coherently coordinated system (CHE, 2004). The higher education system under Apartheid law was inherently inequitable and it was designed to "reproduce white[10] and male privilege, and black[11] and female subordination in all spheres of society" (Badat, 2003: 13). Accordingly, black people, as the largest South African demographic group, had the lowest participation rate in higher education (CHE, 2004). The effects of a disjointed system were observable at institutional level, and higher education institutions themselves became implicated (willingly or not) in perpetuating the apartheid system of "privilege and penalty, of opportunity and stricture, of advantage and disadvantage" (CHE, 2004: 230).

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[10] and [5] Like Wilson-Strydom (2012), I make use of the black and white 'race' categories commonly used in South Africa. While I do not subscribe to racial classification, the extent of injustice remaining following the long legacy of Apartheid and racial classification in South Africa demands that these categories be used (with care) when discussing the social injustices experienced by students in higher education (Wilson-Strydom, 2012).

Higher education in Germany has also been characterised by a differentiated and segregated system. From 1933-1945 under totalitarian leadership by the Nazi Party, apolitical scholarship was not allowed, and the Nazi regime insisted that university activities be pursued in accordance with its official political principles and aims (Hearnden, 1976). During this period, higher education in Germany was highly centralised. However, not long after the end of World War II and the fall of Nazism, the country became geographically divided into East (Democratic Republic) and West (Federal Republic) Germany through the erection of the Berlin Wall in 1961 (Hearnden, 1976).

Despite their common roots, university and higher education in East and West Germany took very different paths since the end of World War II (Mitter, 1990; Nugent, 2004). The systems were differentiated on almost all levels, including secondary schools, access, research and teaching (Nugent, 2004). The higher education systems were also differentiated according to their goals and value orientation, legal order and curricula (Mitter, 1990).

In the East, the school system was more unified than in the West (Nugent, 2004). Furthermore, since the end of the 1960s, the German Democratic Republic had instituted a strong separation of research and teaching in the realm of higher education and training (Nugent, 2004). According to Nugent (2005), academic research in East Germany was carried out by academies of science, and universities were reduced to teaching institutions with curricula strongly tied to the ideals of the ruling Communist Party, the *Sozialistische Einheitspartei Deutschlands* (SED). As a result, the structural and administrative nature of university study in the East was controlled and 'school-like' (Nugent, 2004). That is, in East Germany the establishment of a 'socialist' regime was followed by the "consistent adjustment of the education system to the uniform political and ideological power structure and, manifested by an articulate, gradually achieved, retreat from what was called the 'bourgeois' past" (Mitter, 1990: 333). On the other hand, in West Germany, policy-makers and educationalists largely adhered to the *Grundgesetz* (Basic Law) and the constitutions of the *Länder* (States) that lay the foundation for "teachers and educators to preserve and spread a core of democratic, liberal and social values" (Mitter, 1990: 333).

During the early stages of reintegrating the German Democratic Republic into the system of the Federal Republic of Germany, the entire educational system in the East was re-evaluated from primary schools to advanced scientific research. Although the main academic concern was the reconstruction of universities, the leitmotif behind the push for university reform was modernization. Moreover, although the main idea behind modernization was economic, the concept of modernization meant the establishment of equal opportunity for groups that, up to that point, had been hindered from higher education participation based on the perception of their rights as citizens (children of the working class, Catholics, some members of the provincial population and women).

As the next section will show, student activism and student protests have often served as catalysts for change, not only during periods of reconstruction, but also decades afterwards. The purpose of this chapter is thus to reflect on ways in which universities in Germany and South Africa have cultivated agentic students who under trying periods of social change within their nations, managed to catalyse positive change. Therefore, this chapter does not offer a comprehensive socio-historical discussion of the two countries, instead, it draws from specific occurrences in both countries in order to contextualise social change that was catalysed by university students. The section thereafter, provides more background information on education in both countries, for orientation and contextual purposes.

2.2 Student activism as catalysts for social change

2.2.1 South Africa

The conditions prevailing at historically disadvantaged institutions in South Africa during the 1960s promoted the growth of student politicisation (Reddy, 2004). By the 1970s, black universities were, without intending to do so, creating the space for young students to voice and act on their political frustrations (Reddy, 2004). These institutions were gradually transformed into terrains of political struggle by student organisations and campaigns, but the resistance was not uniform (Reddy, 2004). Periods of relative calm and stability were followed by a breakdown of normal classes when student protest was embarked upon (Reddy, 2004). In accessing their various roles in social transformation in South Africa, the space the historically black universities created for political resistance contributed to the collapse of Apartheid by becoming key centres of the civic uprisings during the 1980s (Reddy, 2004).
At the same time the mainstream of historically white universities played conservative, even reactionary roles, while black higher education institutions (by the nature of the repressive design envisioned by Apartheid planners) created conditions conducive to politicise black students (Reddy, 2004). For example, black institutions directly increased the size of the black middle class with the formation of ethnic colleges (Reddy, 2004). This emerging black middle class of the 1960s (due to conditions of study, apartheid legislation, and the racist

ideology of the society) found their expectations frustrated they played a crucial role in regenerating internal resistance movements that reached significant proportions in the 1980s (Reddy, 2004). The growing trend of the black middle class has continued in the post-1994 period with many more opportunities for upward social mobility (Reddy, 2004). Graduates from both black and white universities have taken jobs in the state, private sector and civil society, they have moved into former white neighbourhoods, and participate in civil society structures formerly reserved for whites (Reddy, 2004). In this middle class sense, some public spaces in South Africa have become deracialised and universities, in the creation of the emerging black elite, can be held indirectly responsible for this social impact (Reddy, 2004).

It can therefore be argued that the culture of democracy, of values of tolerance and the respect for citizens' rights have slowly taken root in South Africa and universities, which were once directly active participants in the racist Apartheid project (Reddy, 2004). That is, universities have contributed to a new, more democratic culture. However, racist practices in South Africa still continue in a multitude of forms, affecting all classes of blacks (Reddy, 2004). Those among the poor and the working class daily bear the brunt of such abuse (Reddy, 2004). Many from these groups find it difficult to get into higher education institutions because they are unable to afford the fees (Reddy, 2004) and conservative, exclusionary policies and practices remain embedded in the institutional culture of some universities.

As Poggi (2015) argues, it is undoubtedly important that institutions be preserved but they must also recognise when it is necessary to 'move with the times'. Since 1994, there has been only a slow and basic conformity with affirmative action requirements (Poggi, 2015). Universities have registered more students of different races, hired more black, coloured and Indian academic and administrative staff, but in reality, universities have not changed much at all (Poggi, 2015). Language policies still alienate students who do not speak English as a first language (Poggi, 2015). Campuses are multiracial, but classrooms and curricula remain largely dedicated to one way of seeing the world through a lens of Eurocentric cultural domination and globalisation (Poggi, 2015). This has contributed to distancing some African students from academic spaces (Poggi, 2015).

According to Poggi (2015), for more than two decades, any dialogue about change and 'decolonisation' at South Africa's universities has been smothered. At universities like the University of the Western Cape, regular boycotts took place in the 1990s with students protesting against the university excluding students at the beginning of each year for non-fee payment (Reddy, 2004). The fees struggle also brought other issues to the attention of students:

- The continued poor quality of student resources at historically black universities (in comparison to the historically white universities);
- Failure to change the curriculum sufficiently to move beyond Eurocentric paradigms;
- The lack of alternative forums of democratic governance at these institutions, and

a host of other alternative ideas constituting post-Apartheid institutions (Reddy, 2004).

However, by the late 1990s the student movement showed signs of growing weakness as fewer students actively participated in student organisations and student collective action (Reddy, 2004). Issues that had animated students in other parts of the world around this time (privatisation, anti-globalisation, environmental issues, identity politics, public space etc.) did not develop into a serious agenda for the South African student movement (Reddy, 2004). However, the year 2015 marked a resurgence of South African student activism and protest over issues such as high student fees, exclusionary language policies, and calls for decolonising universities.

Student movements that garnered significant media coverage and sparked academic debates include the '#Rhodes Must Fall' and '#Fees Must Fall' campaigns as well as the *Luister*[12] documentary. In chronological order for the year 2015:

— In March, students at the University of Cape Town created the Rhodes Must Fall movement in a bid to campaign for institutional transformation. As a symbolic gesture to mark the institution's response to calls for transformation, students demanded the removal of a Cecil John Rhodes[13] statue from the campus.

— In August, Stellenbosch University students released a controversial documentary film on You Tube called *Luister*. The documentary exhibits students' experiences of, and opinions on, racist and exclusionary ideology and practices that undercut the purpose and role of higher education in a democratic South Africa.

— In October, nation-wide student protest spreads across the country, in support of the Fees Must Fall campaign, where university students called for a 0% increase of tuition fees in the 2016 academic year.

The South African government declared there would be no university fee increases in 2016.

[12] *Luister* is the Afrikaans word for 'listen'.

[13] Cecil John Rhodes (1853-1902) was Prime Minister of the former Cape Colony and he was a British colonial-era businessperson, mining magnate, and politician in South Africa. He is notoriously associated with controversial acts of advancing British Imperialism and upholding racist ideology in Southern Africa.

2.2.2 Germany

As a result of the of World War II, many universities across Germany lay in ruin, and years of control by the National Socialist Party had left a void of academic personnel (many of whom had been driven into exile or executed) (Nugent, 2004). According to Nugent (2004), the 'indisputable political and moral betrayal' of German universities and academics during the Nazi regime provoked numerous questions about the 'ethical and political values' of university study and academic and scholarly work. That is, the failure and demise of German universities under Nazi rule fostered active reform discussions among the countries leaders and academic personnel during the period of reconstruction (Nugent, 2004).

On May 23, 1949, the *Grundgesetz* was signed into power, forming the Federal Republic of Germany. The Basic Law stipulated that the control of education would be divided in a balance between the Federal Government and *Länder* (State) governments. The newly founded Federal Republic of Germany avoided strong central control over education on account of the extreme centralized control of education under the National Socialist Dictatorship (Nugent, 2004). As such, 'denazification,' 're-education,' and 'democratization' were central issues in discussions on public education during the post war climate (Nugent, 2004).

Despite a number of innovative ideas, few to none were implemented (Nugent, 2004). Instead, in the rather hectic political climate of reconstruction, expansion, and economic growth, the academic community looked back to the 'Humboldtian[14]' university ideal of the early 19th century with renewed reverence (Nugent, 2004). Therefore, despite the climate of modernization in society, traditionalism prevailed in education policy (Nugent, 2004). Despite the expansion of facilities and teaching staff, universities were not able to accommodate the expansion of students as originally planned, and by the mid-1960s universities were 'overcrowded and inefficient' (Nugent, 2004). Overcrowding and underfunding did not only affect the teaching environment (congested lecture halls, inaccessible professors etc.), it also affected a key issue at the core of the German university ideal: the ability for students to carry out independent research (Nugent, 2005). Additionally, lengthy study duration and climbing dropout rates triggered alarm signals, resulting in

[14] 'Humboldt's ideal of education' often refers to the central idea of the combination of research and teaching at universities and other higher education institutions. The phrase is named after Wilhelm Freiherr von Humboldt (1767-1835), who is known for his promotion of school and university system reform according to humanist principles. He also advocated that schools and universities should be fundamentally 'neutral'- free from ideological influences and government or private interests.

renewed discussions about substantive structural changes (Nugent, 2004).

Plans put forward by the *Wissenschaftsrat*[15] were first met with approval from student groups and the *Westdeutsche Rektorenkonferenz*[16] (Nugent, 2004). However, soon afterwards this support turned into opposition as increasing numbers of professors began to protest because they felt that the recommendations to increase government administrative control in universities ran against the traditional principles of academic freedom and autonomy with respect to research, teaching, and learning (Nugent, 2005). The proposed controls also acted as a detonator of student movements. University reform, according to student groups, should not have meant increased administrative control of students' study behaviour, but rather a fundamental change to the 'old oligarchical political decision-making system' within universities (Nugent, 2004). Student interest in political-administrative reform shifted the emphasis on university reform in Germany to one more focused on democratizing decision-making (Nugent, 2004). As a result, debates over the democratization of university administration dominated the discourse about university reform until the beginning of the 1970s (Nugent, 2004).

In 1966, faced with an economic recession, the two major West German political parties *Sozialdemokratische Partei Deutschlands* (Social Democratic Party; SPD) and *Christlich Demokratische Union* (Christian Democratic Union; CDU) came together to form what came to be known as the Grand Coalition (Medeiros, 2012). Their decision to allow Kurt Georg Kiesinger of the CDU to serve as chancellor proved controversial, as Kiesinger played an active role in the foreign ministry under the Third Reich (Medeiros, 2012). According to Medeiros (2012), the Great Coalition's reform proposals were also criticized for being non-democratic. Their proposal to reform German universities and make the nation more competitive seemed to ignore students, who demanded a voice in the procedure. Students thus resisted changes that allowed the government to limit graduation requirements in order to produce more graduates faster as a part of its economic plan (Medeiros, 2012).

Particularly at German universities, young students felt constricted by a life of the bourgeoisie and became part of the German student movement (Schenck, 2006). They demanded global justice and dreamed of world peace. They felt that the economic wealth of

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[15] The *Wissenschaftsrat* is the German Council of Science and Humanities, which provides advice to the German Federal Government and the government of the German *Länder* (Federal States) on the structure and development of higher education and research.

[16] Established in 1949 as the '*Westdeutsche Rektorenkonferenz'* now known as the '*Hochschulrektorenkonferenz'* (HRK), following the unification of East and West Germany in 1990.

the nation following the German *Wirtschaftswunder*[17] (Economic Miracle) of the 1950s led to an ever growing gap between the rich and the poor instead of improving the standard of living of the working class (Schenck, 2006). The youth criticised Germany's and their parents' 'fascist' past, and rebelled and questioned authoritarianism and hypocrisy of family, society, and government alike (Schenck, 2006). The German student movement followed more than a century of conservatism among most German students and demonstrated a noteworthy shift towards the left and radicalization of student politics (Schenck, 2006). The rejection of the dominant social orders in both the socialist East and capitalist West, and support for anti-imperialist perspectives shaped much of the theoretical and practical developments that followed (Trnka, 2003).

A wave of protests swept Germany from 1966 to 1968. They were fuelled by violent confrontations of protesters versus police, and were encouraged by contemporary protest movements in the world[18]. Students protested against war, US imperialism, fascist tendencies of West German politics (especially the police) and the rule of the capital (Cornils, 2003; Schenck, 2006). According to Cornils (2003: 298):

> Even though the German Student Movement only lasted for two years, it holds a lifetime of 'magic moments' for the individuals who were part of it. It is portrayed as an era imbued with a unique hope and a common counter-cultural agenda: the dream of what might be possible if a whole generation were to refuse to accept traditions and refuse to replicate their parents' values.

Besides the student movement of 1966-1968, many other student protests have taken place in Germany, which resulted in notable social change. To name a few, in chronological order from the mid-1960s:

— In June 1966, 3,000 students from the Free University of Berlin staged a sit-in below the window of the hall where the school senate, consisting of a rector, professors, and other college administrators, was holding a meeting on proposed resolutions such as limiting class requirements and giving administrators enhanced powers to expel students. Students demanded transparency and inclusion of the student senate in the proceedings. They called for the need to democratize the university system and society in general, fighting for the right to study longer and to express themselves and

[17] The *Wirtschaftswunder* is also known as 'The Miracle on the Rhine' and it describes the rapid reconstruction and development of the economies of West Germany and Austria after World War II.

[18] During the 1960s, different parts of the world (but mainly global North countries) developed countercultures that spurred the development of movements such as The Free Speech Movement and 'New Left' movements, or the Anti-War, Anti-Nuclear movements, and Feminism movements.

be heard (Medeiros, 2012).

- In 1999, Germany's free education movement began with the founding of the Alliance Against Tuition Fees. 200 organisations including student unions, trade unions and political parties came together to declare their commitment to fighting for free education. This movement continued in the mid-2000s, with students taking to the streets all over Germany in response to the seven West German states that had re-introduced fees (Hermanns, 2014; Smith, 2014).
- In 2008, students started protesting in their hundreds in Bavaria and they organised radical occupations, debates in schools, election campaigns and events in wider community (Hermanns, 2014).
- In 2009 hundreds of university students staged demonstrations across Germany in protest against tuition fees. Demonstrators held sit-ins at lecture halls in 20 German cities including the Free University of Berlin and Munich's prestigious Ludwig Maximillians University. Protesters wanted tuition fees, which were between 100 to 500 euros[19] per semester, to be scrapped. They also wanted scholarships to be made available to poorer students based on need rather than academic achievement. The demonstrations also opposed reforms to harmonise the German degree system with the rest of Europe.
- By 2013 the number of student protesters had grown into the high thousands and public opinion had changed so much in their favour that they delivered a successful petition for a state referendum on higher education policy: 1.35 million eligible voters signed it (circa 15% of the population) (Hermanns, 2014).

To sum up, in focusing on the relationship between universities and social transformation, South African and German universities (like universities elsewhere), tend to assume multiple roles. They serve various constituencies, and respond to social injustice within their borders in different ways, and they react differently to established social patterns found in society (Reddy, 2004).

In looking at the roles of universities in the fall of socially unjust and divisive national governance, and in the social transformation of post-Apartheid South Africa and post-Nazi Germany, it is inaccurate to view higher education institutions as homogenous entities. Within individual institutions, even within individual academic departments, roles played are multiple and sometimes contradictory (Reddy, 2004). Both reproductive and transformative

[19] At the time, this translated into approximately $150 to $750 (US) or R1 239 to R6 195 (SA) per semester.

tendencies can be identified in various degrees in South African and German higher education. For example, in South Africa, universities have contributed in significant ways (albeit not necessarily intentionally) to the reproduction of Apartheid racial social order (Reddy, 2004).

It is therefore clear that seeking changes in universities is a highly complex endeavour to be pursued with: modest claims about planning ambitions; measured accounts about institutional contexts; and moderate expectations about sustainability (CHE, 2007).

It is also clear that the challenge of widening access to universities and establishing a new higher education terrain is not unique to South Africa. A brief look German higher education history reveals a number of similarities to the situation experienced in South Africa at the end of Apartheid. This is evident in the trends of student activism and protest that have taken place in both countries during periods of social reconstruction. The main difference lies in the chronology of events as mapped out in the socio-historiography of both nations.

While the German 'no tuition fee' campaign began in 1999 and significantly contributed to university tuition fees finally being scrapped in 2014, in South Africa, students and many academics are currently frustrated with high fees (as well as a teaching body that remains stubbornly white and male, and curricula that need more relevance in an African country) (McKenna, 2015). According to McKenna (2015), student movements such as #Fees Must Fall are not only a call for change at institutional level; they are also reactions to what authors such as Vally and Motala (2014) call the failure of the human capital model of education.

As this section has shown, it is important not to neglect the potential that higher education institutions have to fight social injustices, because there are many ways in which university structures can challenge the value systems of the state (McKenna, 2015). Moreover, this section has also drawn attention to universities' potential for developing critical masses of students, who are able to exercise their voice and agency to effect change in society that they have reason to value. It can therefore be argued that universities have the potential to develop critical engineering professionals who can use their knowledge, skills, effective power, and agency for their own well-being and for the public good.

2.3 Education in Germany and South Africa: Policies, structures and administration

2.3.1 Policy objectives

As South Africa entered a process of social, economic and political reconstruction in 1994, it was clear that merely reforming limited aspects of higher education would be insufficient to meet the challenges of a democratic country aiming to take its place in the world (CHE, 2004). Rather, a comprehensive transformation of higher education was required, marking a fundamental departure from the socio-political foundations of the Apartheid regime (CHE, 2004). Redress of past inequalities in higher education was a central issue in policy debates from the early 1990s, and was identified as a policy goal in the White Paper and National Plan (CHE, 2004). The first period of policy activity from 1990-1994 was primarily associated with 'symbolic' policy-making, where the intention was to declare a break with the past and signal a new direction, and the second period from 1994-1998 focused on framework development (CHE, 2004).

A third period of policy-making began in 1999, as efforts turned to policy implementation (CHE, 2004). This was a period in which there were calls for more targeted, differentiated, information-rich policy interaction between government, higher education institutions and society (CHE, 2004). However, a relatively hands-off approach or poor governmental steering (which essentially left it to individual higher education institutions to take the lead) resulted in a lack of tangible progress at this time (CHE, 2004). Therefore, transcending the apartheid legacy in higher education by establishing a national, integrated and coordinated yet differentiated system remains a key policy objective, along with restructuring the institutional landscape and establishing a comprehensive funding framework (CHE, 2004).

While transformative changes in South African higher education policy have been influenced by international trends, there is scant reference to internationalisation in key higher education policy documents, meaning that the issue has not received optimal policy attention for the purposes of maximising the benefits of collaboration in an international frame (CHE, 2004). In contrast, internationalisation has been a key policy issue in Germany and the main drive of contemporary university reform measures.

In 1998, the Sorbonne conference took place in Bologna, Italy, where ministers in charge of higher education from Germany, France, Italy, and the United Kingdom met to initiate the harmonization of the European higher education system. It was generally agreed on that the national systems of higher education in Europe had proven to create hindrances that prevent the mobility of students and employees, because degrees were most often awarded and accredited solely on a national basis (although they needed to be recognized by the international labour market) (CESAER & SEFI, 2005; Harriehausen, 2005; Heitman, 2005).

It was also agreed on that the attraction of European higher education to students and academics from other parts of the world had continuously decreased because of problems with the external and internal readability of degrees (Allegre, Berlinguer, Blackstone, & Rüttgers, 1998). The 'Bologna Declaration' was published in 1999, with the main objectives to: create a common European Higher Education Area (EHEA); enable mobility for students and teachers at an international level; and promote the mutual recognition of grades and exams across the member countries (Bucciarelli, Coyle, & McGrath, 2009; Lucena, Downey, Jesiek, & Elber, 2008; Nugent, 2005). Other objectives included:

- The adoption of a system essentially based on two main cycles, undergraduate and graduate.
- Establishing a system of credits-such as in the European Credit Transfer System (ECTS) as a proper means of promoting the most widespread student mobility.
- Promoting European co-operation in quality assurance with a view to developing comparable criteria and methodologies (Molzahn, 2004; Nugent, 2005)

As one of 47 countries participating in the Bologna Process, Germany has implemented the two-tier structure of Bachelor and Masters Degrees.

Education lies at the centre of government's plans for development. This is made clear in government planning documents such as the:

- South African National Development Plan (NDP);
- South African National Strategy for Sustainable Development and Action Plan (NSSD1); and
- German National Sustainable Development Strategy (NSDS),

which all emphasise the vital role education plays in achieving national and (global) sustainable and millennium development goals (see DST, 2013; DST & BMBF, 2013; NDP, 2012; NSDS, 2012; NSSD1, 2011; RNE, 2005). This is largely due to the fact that there is considerable theoretical and empirical literature demonstrating the benefits of education for economic growth (DBE, 2013). The theoretical underpinnings for this lie in the human capital model (see Becker, 1962; T. W. Schultz, 1961), according to which investments in human capital should improve the productivity of the labour force, increase the innovative capacity of the economy and facilitate the transmission of new knowledge and technologies (DBE, 2013).

In South Africa matters of 'access and success' are key policy issues. Efforts to reform the higher education landscape are particularly concerned with creating opportunities for students from previously disadvantaged backgrounds to thrive in higher education. This has resulted in a more racially and culturally diverse student population. Germany faces similar challenges of dealing with more culturally diverse student populations, because of the implementation of the Bologna process. This has prompted the HRK, with the support of the

Federal Ministry of Education and Research (BMBF), to launch a project to help universities with the continued implementation of the European Study Reform (HRK, 2013b). The project 'Nexus- Forming Transitions, Promoting Student Success' facilitates 'improved access to universities for students with different biographies and backgrounds' in order to help them achieve success (HRK, 2013b).

It is also worth mentioning that Germany has a large Turkish community, and recently, immigration numbers have risen sharply. In this sense, the objective of diversifying the student population in higher education is common to South Africa and Germany. The difference primarily lies in the fact that in South Africa, it is largely a national issue (access for South African students to South African higher education), whereas in Germany it is an international issue taking place within the broader landscape of the EHEA (access for EU and international students in German higher education).

The increasing heterogeneity of the student body is both a challenge and an opportunity for the higher education institutions in Germany and South Africa. This gives teaching an important additional dimension, which changes the composition of the student body, which is increasingly characterised as heterogeneous (HRK, 2013b). Reasons for increased diversity in are the sharply rising number of students and successful attempts by universities to provide more equal opportunities and make studying for a degree more inclusive (CHE, 2004; HRK, 2013b).

2.3.2 Education structures

South African and Germany differ in the structure of their education systems and in the strength of the link between education and the labour market. Germany has a highly selective education system based on early selection into vocational and academic education tracks and strong links between education and the world of work (Iannelli & Klein, 2014). A small proportion of secondary school students enter the higher education system, and for those who graduate, the transition to the labour market tends to be smooth (Iannelli & Klein, 2014).

Selection to university study occurs first through the separation of pupils based on their performance in primary school into three separate secondary tracks:

1. *Hauptschule,* which lays the groundwork for vocational and industrial training;
2. *Realschule,* which prepares students for higher vocations; and
3. *Gymnasium,* which gears students towards academic study.

Another type of secondary school available in some German states is the *Gesamtschule*, or comprehensive school. The *Gesamtschule* accepts students of all academic abilities and awards those students who finish in the ninth grade a *Hauptschule* certificate (number 2. above) and those who finish in the tenth grade a *Realschule* certificate (number 3. above).

This three-way division of German secondary schools tracks pupils into essentially three social and occupational strata, the highest being the academic. Immediately following the war, this educational structure was criticized as elitist and undemocratic (Nugent, 2005). Despite this fact, many countries envy Germany's vocational training system; it is said to be one of the main reasons why Germany's youth unemployment rate (8.1%) remains well below that of the EU average (23.4%) (BMBF, 2013, 2015). This is because many young people transition from secondary education institutions into dual training and then into employment (BMBF, 2013). The dual training system has proven to be stable and productive even in the face of economic and financial crises (BMBF, 2013).

In Germany, social inequalities are transmitted mainly via education, both through early selection into an academic or vocational track and through the choice of subject a student makes (Iannelli & Klein, 2014). Vocational education and training (VET) connects educational and economic aims (Sloane, 2014). Philosophically, it means that education can be fostered by work as well as by schools (Sloane, 2014). For example, students who have attended either the *Hauptschule* or *Realschule* can then go on to a *Berufschule*, which pairs academic study with apprenticeships. Once the apprenticeship is complete, students who pass their final exams are awarded a certificate for a specific line of work. This curriculum is overseen by the federal government, trade unions, and industry organizations. On the other hand, students who attend the *Gymnasium* and acquire an *Arbitur*[20] certificate may apply at universities (i.e. *Hochschule*[21], *Fachhochschule*[22] or *Universität*[23]).

In South Africa, the National Qualifications Framework (NQF) recognises three broad bands of education: General Education and Training; Further Education and Training; and Higher Education and Training (DBE, 2013). School life spans 13 years or grades (from grade 0 to grade 12 or 'Matric'- the year of matriculation). General Education and Training runs from grade 0 to grade 9. Further Education and Training covers grades 10 to 12, and includes career-oriented education and training offered in Further Education and Training institutions

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[20] An *Abitur* is a school leaving certificate issued upon successful completion of the 12th grade or *Gymnasium* exams.

[21] *Hochschule* refers to higher education institutions such as universities, colleges or institutions that are not authorized to confer doctorates.

[22] *Fachhochschule* refers to Universities of Applied Science or higher education institutions specialising in specific fields like technology and engineering.

[23] *Universität* refers to traditional, academic, or Humboldtian universities that are authorised to confer doctorates, and generally combine teaching, learning, and research to advance academic scholarship.

(FETs) - technical colleges, community colleges, and private colleges (DBE, 2011, 2013). Diplomas and certificates are qualifications recognised at this level. Some private schools also offer post-matric courses that allow students to sit for A-level[24] examinations (DBE, 2013).

South African universities offer a combination of academic and vocational diplomas and degrees, while the country's universities of technology focus on vocationally oriented education. Some also offer theoretically oriented university degrees. Depending on the grades achieved in matric, students may qualify for admission to universities. Those who do not complete school to the 12th grade can enrol in institutions such as FET colleges that cater for out-of-school youth and adults.

Existing at the cross roads between compulsory education, higher education and the world of work, South Africa's public FET colleges aim to respond to the skills needs of the South African economy (Powell, 2012). Simultaneously, they are to respond to the social disparities by providing disadvantaged communities with access to high quality and relevant education and training that provides capacities for employability(Powell, 2012). Within the context of insufficient jobs in the formal economy, this involves training for entrepreneurship and for the informal economy (Powell, 2012). As such, FET and VET colleges have an important role to play in providing alternative access routes to higher education or to gaining skills for employment (Akoojee, Gewer, & McGrath, 2005; McGrath, 2010).

2.3.3 Number of universities and student populations

Since 1994, there have been numerous changes to the university terrain. Smaller universities and 'technikons' (polytechnics) were incorporated into larger institutions to form comprehensive universities. South Africa currently has 25 public universities. These comprise of 11 traditional universities, six comprehensive universities[25] (DHET, 2013) and eight universities of technology (two of which only began operating in 2014). There are also two institutes of higher education which serve as administrative hubs, co-ordinating higher education provision through partnerships with universities and (DHET, 2013). The 2011 student head-count for the 23 operational universities at the time was 937 455 (which includes full-time and part-time enrolments) (DHET, 2013). This represents nearly a doubling from 1994, when the head-count was 495 356 (DHET, 2013).

[24] The General Certificate of Education Advanced Level, commonly referred to as the A Level/s, is a school leaving qualification offered by educational bodies in the United Kingdom to students completing secondary or pre-university education.

[25] Comprehensive universities combine the functions of traditional universities and universities of technology

Since the end of World War II, the number of people in university has more than tripled in Germany. Nevertheless, university attendance is lower than that of many other European nations. This is partly because of the dual education system, with its strong emphasis on apprenticeships, and because many jobs which do require a degree in other countries (like nursing) only require a qualification from a higher education institution such as a *Krankenschwesternschule* or Nursing School (which is not regarded as a university). In contrast with the 25 universities in South Africa, there are currently 331 higher education instituions in Germany[26], with a combined student population of approximately 2.4 million (HRK, 2013b). Of these, 110 are traditional universities (or similar institutions) and 221 are universities of applied sciences or *Fachhochschulen* (HRK, 2013b).

2.3.4 Funding, governance and institutional autonomy

Due to the federal system in Germany, responsibility for education, including higher education, lies with the individual 16 *Länder* or federal states (HRK, 2013b). The states are responsible for the basic funding and organisation of higher education institutions and each state has its own laws governing higher education (which means the actual structure and organisation of the various systems of higher education may differ from state to state) (HRK, 2013a). Higher education institutions have a certain degree of autonomy regarding their organisation and in deciding on academic issues (HRK, 2013a). In the last two decades, this autonomy has been increasingly broadened to include issues related to human resources and budget control (HRK, 2013a).

However, as a strongly centralized state system, the SA Constitution determines the overall parameters for all other legislation, national or provincial. For education, the first challenge was to align the governance of a fragmented and uncoordinated plethora of racially defined separate subsystems into a uniform national system, especially as regards primary and secondary schooling. Consequently the first decade after 1994 saw the roll-out of new legislation to standardize and redefine the education system: more than thirty Acts and Amendments were implemented over this initial period (DBE, 2013). According to the Department of Basic Education (DBE), key legislation included:

- The South African Qualifications Authority Act (Act 58 of 1995), which established a National Qualifications Framework (NQF);

[26] These differences should be considered in relation to each country's population numbers. The 2015 mid-year population estimate for South Africa is 54,96 million (Statistics South Africa, 2015), while Germany's stands at 81.30 million (Federal Statistical Office of Germany, 2015).

- The National Education Policy Act (Act 27 of 1996), which laid out broad features of policy for democratic transformation, while other legislation introduced changes to the content and methodology of curriculum, introducing Curriculum 2005 and Outcomes Based Education;
- The South African Schools Act (Act 84 of 1996), which aimed at a uniform system for the organisation, funding and governance of schools; and
- The Higher Education Act (Act 101 of 1997), amended in 2000 and 2001, which redirected and consolidated government policy for all tertiary education administered under the central Ministry.

The main innovation in education after 1994 was that public schooling for all children was centralized within a uniform system, in which nationally determined policy was implemented at provincial level. In 2009, the Department of Education was split into two departments with respective minsters: 1) the Department of Basic Education (DBE), which is responsible for primary and secondary education i.e. the school system; and 2) the Department of Higher Education and Training (DHET), which is responsible for the post-school/tertiary/higher education system (DBE, 2013).

Schools and public universities are partially funded by budgetary allocations that are determined at national level (DBE, 2013). The Constitution specifies that pre-tertiary education is a concurrent function where the national and provincial governments share the responsibility. According to the 1996 National Education Policy Act, national government is responsible for establishing broad policies and the necessary monitoring systems. Provincial governments and, more specifically provincial departments of education, are responsible for establishing and funding schools in line with provincial needs (DBE, 2013).

More than the physical alterations or programmatic reforms, the most far-reaching changes in universities have been the gradual erosion of institutional autonomy and the corresponding growth of accountability regimes[27] in the higher education system (CHE, 2007). These changes have essentially altered the value and significance of 'the academic estate' (Altbach, 2000, as cited in CHE, 2007: 164).

[27] An example of an accountability regime is reflected in the duties of the Department of Performance Monitoring and Evaluation (DPME) that has been established by the Presidency. The DPME signs performance agreements with cabinet ministers in order to hold them accountable for measurable targets, as a way to ensure greater accountability (DBE, 2013).

2.4 Summative discussion

This chapter has shown that Germany and South Africa are countries with significant differences in terms of their education systems and higher education terrains (amongst other things). However, they have faced similar challenges in terms of having to reform their universities and rebuild their societies so that they may be more socially just institutions in which *all* their citizens can live and learn. Looking at the role of universities during periods of transformation in German and South Africa societies it is clear that governments grapple with what Nugent (2004) refers to as 'seemingly opposing and contradictory ideologies within traditional and novel structural frameworks'. Over time, the goals towards which higher education policies are aimed change according to the political and socio-political conditions of the time.

As mentioned in chapter 1, as developing country, South Africa is characterised by absolute levels of poverty, high unemployment rates, and extremely high inequality (UN DESA, 2015), which are chronic problems in the country (DBE, 2013). Wealthy, highly industrialised and developed countries like Germany bear responsibility not to pass on 'social and ecological burdens' to developing countries (NSDS, 2012). This is because global resources are insufficient for the whole world to be able to model itself on industrialised countries, which means not all people can experience the same standard of living as that which developed countries currently enjoy.

Although countries at different stages of development should prioritise national objectives according to their respective urgent needs, the ideal and challenge to create a more socially just world is transcends the borders of nation states. As such, both global North and global South countries need to take necessary action to ensure that education enables people not only today, but also in the future to "live in a world in which economic prosperity for all goes hand in hand with social cohesion and the protection of natural resources" (NSDS, 2012: 17). That is, in a world that recognises a commitment to intergenerational equity and the peaceful coexistence of people (NSDS, 2012).

Therefore, while there is value in conducting comparative research, one of the things that make the work of this thesis unique is the exploration of German and South African perspectives together. Instead of comparing these views, they are combined in the hope that this will result in rich data that can enhance the normative conceptualisations of engineering education proposed in this thesis. Furthermore, diverse and multiple perspectives have the potential to create nuanced understandings of the issue at the heart of this work. This thesis recognises that German and South African perspectives can offer particularly interesting views on the same issue: how engineering education in universities contributes to sustainable human development. After all, sustainable human development is not a concern that matters more or less in the global North or South. It is a universal concern.

Chapter 3

Review of literatures on engineering education in universities

3.1 Introduction

Engineering involves the purposeful application of mathematical and natural sciences knowledge, and a body of engineering knowledge or technology and techniques. It seeks to produce solutions whose effects are predicted to the greatest degree possible in often uncertain contexts (Clarke, 2012: 2002). While bringing benefits, engineering activity also has potential adverse consequences and must therefore be carried out responsibly and ethically, use available resources efficiently, be economic, safeguard health and safety, be environmentally sound and sustainable and generally manage risks throughout the entire lifecycle of a system or product (IEA, 2009).

The complexity and interdisciplinary nature of engineering activities makes educating them equally complex. An important consideration which is being addressed in studies such as that of Griesel and Parker (2009) is the match or appropriateness of graduate attributes for industry. In their baseline study on South African graduates from the perspective of employers Griesel and Parker (2009: 23) report that there are gaps between employer expectations and higher education outcomes. Engineering is one of the critical scarce skills in South Africa (De Koker, 2010; Lawless, 2005). According to Case (2006), various studies, reports and policy statements have over many years echoed the conviction that there a general shortage of engineers. In South Africa, shortages in the engineering field in general (Akoojee et al., 2005; du Toit & Roodt, 2009; Erusmus & Steyn, 2002) and particularly in the civil engineering arena have been reported (Oosthuizen & Nienaber, 2010). There is a huge demand from industry, but the supply of graduates does not equate that demand in terms of adequate, appropriate skills and numbers (de Koker, 2010). As a developing country, South Africa needs to - for the sake of the economy, and for the profession - attract the majority of our graduates into conventional engineering work (Case, 2010).

Over and above the urgent need for engineers in developing regions, is the need for engineers globally to take on roles as agents of social justice. As Case (2010) argues, the more engineering graduates we have in government, in the financial sector, in the NGO sector, in education, and so forth, the more healthy a society we will have. The review of literature presented in this chapter explores the education of engineers, reflects on what universities are doing, and have done, to develop engineers who can take on such roles in society.

3.2 A brief history of engineering and engineering education in universities

According to Picon (2004), the first recognisable figure of an 'engineer' emerged during the Renaissance, at the intersection of the medieval tradition of master-builders and specialists of war engines. At the time, the engineer appeared as an isolated figure, an artist working for kings and princes, in a similar fashion to artist painters, sculptors or architects (Picon, 2004). This suggests that at this stage the work engineers did was not particularly distinguishable from a fellow artisan. However, during the second half of the 17th century, when territorial states like France began to organize their military engineers in corps, the way for the emergence of a profession was paved and began to flourish between 1750 and 1850 (Picon, 2004). Although there are various accounts of engineering activities all across the world at this stage (and earlier), it was in France, as early as 1716 that the government established a civilian engineering corps to oversee the design and construction of bridges and roads (Armytage, 1961). This was later accompanied by a school to train this corps known as the Ecole des Ponts et Chaussees (Armytage, 1961; Harwood, 2006; Picon, 2004). The school was founded in 1747 (Armytage, 1961), making it the first recognisable institutionalised form of education and training of engineers.

In the 18th century, virtually all engineers were military personnel, regarded as manual workers with a low status and known as those who are involved in 'engineering for civilians and civilian life' (Carruthers, 2010). This marked the emergence of civil engineering as the first field of engineering to come into its own (Carruthers, 2010). From 1850 onwards the engineering profession is marked by an increasing diversity, with mechanical engineering distinguishing itself from civil engineering, and later with the emergence of electrical and chemical engineering in the 19th century (Clarke, 2012). And although engineering colleges were well established at this point, engineers were also still largely trained through apprenticeships (Clarke, 2012). By the end of the 19th century, engineering came to be considered a reputable profession, one to which even 'gentlemen' might aspire (Carruthers, 2010). At this time, both technical education and the professional organization of engineers were fully developed and engineering comprised four major fields of knowledge and practical application:

1. Civil engineering (construction of canals, railroads and internal improvements);

2. Mining, metallurgy (mines, steel plants);
3. Mechanical engineering (machine building, operation of engines and manufacturing);
4. Electrical engineering (telecommunication and electrical manufacturing),

Today there are numerous sub-fields and branches in engineering, across the fields mentioned above and a further accentuation of the engineering profession is also marked by the growing number of engineers performing managerial functions (Picon, 2004). The establishment of the engineering profession necessitated specific education and training. Although the highly technical nature of the field initially led to a view of engineering as something an individual learned to do through practice, the theoretical aspects grounded in mathematics and science indicated the need for an education which went beyond learning the trade through apprenticeships. In the 1960s, the primary route to becoming a professionally qualified engineer shifted from apprenticeships to degrees, and so the initial stages of developing an engineer took place through higher education as opposed to industry training (Clarke, 2012).

Historically, engineering curricula in universities have largely been based on an engineering science model, in which engineering is taught only after a solid basis in science and mathematics (Dym, Agogino, Eris, Frey, & Leifer, 2005). Although this model prevails today, debates continue about the form, structure, content, duration and purposes of engineering education. Since then, the nature, content, and pedagogies of engineering education continue to evolve, aiming to satisfy the ever-changing needs and demands of society and industry. Furthermore, there are ongoing debates surrounding engineering graduate attributes and the most appropriate education required to achieve them.

While the great debate in the 19th century was about the need for higher education, the debate throughout the second half of the 20th century was about the relevance of that education (Clark, 2012). For example, in 1930, there was a view that engineering degrees were stagnating and that engineering graduates lacked both business skills and practical experience (Clarke, 2012). In 1960 debates ensued about the lack of design skills; communication skills dominated debates in the 1980s; concerns about employability arose in the late 2000s (Clarke, 2012), and today there is increased attention payed to issues of embedding sustainable development in engineering curricula. These debates have often pointed to the need for more attention towards non-technical aspects of engineering practice (summarised in the table under 'soft skills' and transversal skills) which has led to proposals for the inclusion of the humanities in engineering curricula in order to broaden engineering graduate attributes.

Graduate attributes are examples of the qualities expected of graduates as the outcomes from an accredited programme; they are succinct statements of a graduate's expected abilities (IEA, 2009) that represent the kind of knowledge, skills, competencies and values a graduate should possess. These attributes can generally be framed according to three categories: 1) knowledge and intellectual ability; 2) workplace skills and applied knowledge; 3) interactive and personal skills (Clarke, 2012). These three categories are often classified according to 'hard' skills i.e. core technical knowledge and competency which is directly related to and essential for engineering task fulfilment, and 'soft' skills, which are often seen as desirable (but non-essential) dispositions and abilities that engineers should have in addition to technical proficiency. More recently, a third category of skills has been receiving increased attention in educational research, namely transversal skills. These cross-cutting, generic skills are often non-cognitive and transferable to wider practice. Whereas soft-skills tend to be task specific, transversal skills are directly relevant to engineering tasks, but also fundamental to non-engineering doings and beings that characterise individual well roundedness.

The table below summarises descriptions depicting some common engineering graduate attributes found in the South African literature (du Toit & Roodt, 2009; Griesel & Parker, 2009; Knobbs, Gerryts, & Roodt, 2013; Vanasupa, Stolk, & Herter, 2009); and international literature (Boni & Berjano, 2009; Clarke, 2012; Downey, 2005; Lucena et al., 2008; Ruprecht, 1997). Reports by professional bodies such as the Engineering Council of South Africa (ECSA) (see ECSA, 2009) and the German Association of Engineers[28] (VDI, 2007a, 2007b, 2009, 2013, 2014) were also consulted.

Table 1: Summary of general engineering graduate attributes

Technical skills	**Soft skills**	**Transversal skills**
Ability to apply knowledge of basic science and engineering	The ability to function effectively as an individual and	Critical thinking

[28] The German Association of Engineers is known in Germany as the *Verein der Deutsche Ingenieure* (VDI).

fundamentals	in multi-disciplinary and multi-cultural teams, with the capacity to be a leader or manager	
Ability to utilise a systems approach to design and operational performance	Understanding of the social, cultural, global and environmental responsibilities of the professional engineer	Life-long learning
In-depth technical competence in at least one engineering discipline	Understanding of and commitment to professional and ethical responsibilities	Ethical learning
Ability to undertake problem definition, formulation and solution	Ability to communicate effectively, not only with engineers but also with the community at large	Cosmopolitan abilities
	Understanding of the principles of sustainable design and development	

Source: Author's own.

There has been an increase in interest on the development of soft skills and transversal skills for engineers because of the recognition that, engineers have to be able to influence the behaviour of people who implement engineering outcomes if their work is to have sustainable value (Trevelyan, 2014). Failing to do so means that engineers abandon responsibility in influencing how the technological artefacts created by them is impacting the lives of all people. This situation is counterproductive for public-good professionalism, which can be conceptualised according to the opportunities people have to make the choice to contribute professionally to equitable social improvements (Walker & McLean, 2013). Enhancing public-good professionalism in technical studies requires higher education to create both formal and informal spaces in which students' empathy, intercultural respect, critical thinking and self-reflexivity can be fostered (Boni-AristÏzabal & Calabuig-Tormo, 2015). Many studies illustrate the need to incorporate the humanities further in engineering curricula to this end.

3.3 The role of the humanities in engineering education

While history shows a recognition that to be considered professional, some measure of the humanities should be an integral part of the curriculum, it was only in 1939 that the Humanities and Social Sciences were explicitly encouraged to be offered parallel with technical courses in engineering programmes (Bucciarelli et al., 2009). The 1939 report on the aims and scope of engineering curricula that was compiled by the Society for the Promotion of Engineering Education stated, "There are advantages in the parallel development of the scientific-technological and the humanistic-social sequences of engineering education." Additionally, it affirmed that, "When the elements of these sequences are compartmentalized and taught at different stages of the curriculum, they frequently remain unrelated and uncoordinated in the student's mind" (Hammond, 1939: 562). The report also argued that continuous engagement with 'humanistic-social' issues allows students the opportunity to develop adequate understandings of their importance and bearing on scientific-technological subjects (Hammond, 1939).

As the next section shows, there are many convincing arguments in favour of proposals for humanist curricula in engineering studies and inspiration for the development of courses that attend to qualitative problems in engineering education is abundant.

In particular, this body of literature highlights that engineering graduates need to develop and demonstrate attributes commonly referred to as 'soft skills' (da Silva & Tribolet, 2007; Hillmer, 2007; Knobbs et al., 2013; Ziegler, 2007) and transversal skills (Fernandes et al., 2012) in conjunction with strengthening technical expertise.

3.3.1 Cultivating 'soft' and transversal skills in engineering education

The examples discussed in this section do not represent specific recommendations for implementation in terms of infusing the humanities into engineering programmes or teaching so called soft skills. Rather they reflect literature providing diverse and recent approaches applied by various higher education institutions in the global North and global South to amend teaching and learning in university programmes. The hope is to develop values, attitudes and ways of thinking that are conducive to foster public-good engineers or engineers who can function in their professional capacities as agents of sustainable human development.

A good example of a proposal in favour of the integration of the humanities in engineering education is provided by Bissel and Bennett (1997) who convincingly argue for incorporating history into the engineering curriculum. They call for deeper engagement with history about the nature of technology and its complex interrelation with society, politics and economics, arguing that historical chronologies of inventions and inventors sometimes found in engineering textbooks tend to present an over-simplified 'master narrative' of historical development. Bissel and Bennet (1997) posit that such a perspective of the history of technology is counterproductive for future engineers who will need to deal with complex contexts in their professional lives. They also state that it is problematic to teach the kind of history of technology in which the progress of technology from early times to its present magnificence is presented from the standpoint of the present, omitting any examination of false starts or alternative traditions. Bissel and Bennet (1997) therefore argue that a holistic study of the history of technology can offer insight into the nature of technological change, examples of the complex relationship between technology and society, as well as different and valuable perspectives of the subject matter for both learner and teacher.

Bissel and Bennett (1997) posit that in contrast to mathematics and science, where the history of the disciplines has long found a place in university curricula, the history of technology does not feature in many European engineering degrees. In their paper, the authors consider the pedagogical potential of courses offered at a British university, on the history of technology, demonstrating how historical material can enhance the teaching of various topics within the engineering curriculum. For example, studies of 'devices that failed' are included in the course 'Science, Technology & Everyday Life'. Learning about the history of technology develops important generic skills for the engineering profession, because it requires engineering students to think more critically, adopt unfamiliar perspectives and communicate clearly in the learning process (Bissel & Bennett, 1997).

Lucena and Schneider (2008) point out that engineering education initiatives incorporating sustainable development practices are proliferating, and that it thus becomes ever more important to understand the historical lessons of development and the contributions of engineers. In their paper, they provide an outline of the history of engineering practice and education in relation to development, sustainable development, and community development.

Connor, Karmokar, Whittington, and Walker, (2014) challenge some common pedagogies found in Science, Technology, Engineering, and Mathematics (STEM) education with a particular focus on engineering. In their paper, they argue that there is potential confusion in engineering education around the role of active learning-approaches, and that the adoption of these methods may be limited because of this confusion. This is combined with a degree of 'disciplinary egocentrism', which can be defined as the lack of student or staff readiness to engage in multidisciplinary knowledge or apply alternative teaching and learning approaches to the engineering discipline. Connor et al. (2014) give examples of engineering and 'engineering like' projects implemented at a university of technology in New Zealand that demonstrate the effectiveness of adopting pedagogies and delivery methods more usually attributed to the liberal arts, such as studio-based learning. Their paper concludes with some suggestions about how best to create a fertile environment from which inquiry- based forms of learning can emerge.

A study by Boni and Berjano (2009) reflects on the concept of ethical learning as an educational proposal. Boni and Berjano (2009) see ethical learning as a tool to aid individuals to build their own moral dimension according to which they can function effectively and responsibly in both individual and collective settings, and as both professionals in particular occupations, and members of society. They propose the following eight dimensions of an ethical learning educational model:

1. Self-Knowledge: the capacity for progressive knowledge of oneself and the auto-consciousness of the self;
2. Autonomy and self-regulation: the capacity to develop independence of determination and greater consistency in personal actions;
3. Capacity for dialogue: the ability to escape from individualism and to talk about all value conflicts, both personal and social;
4. Capacity to transform the environment: the formulation of contextualized rules and projects in which value criteria related to involvement and commitment are manifested;
5. Critical understanding: the development of a group of abilities directed towards the acquisition of morally relevant information about reality, critical analysis of this reality and the attitude of commitment and understanding to improve it; and,
6. Development of capacity for empathy and social perspective: to have greater consideration for others and interiorize values such as co-operation and solidarity

7. Social skills: interpersonal behaviour learned by the person and social performance in different spheres of relationships with others
8. Moral reasoning: the practice of reflecting on value conflicts.

Setting out from this model, the authors formulate a proposal for ethical learning in the university as follows: “to educate professionals and citizens who build their knowledge individually and act in a responsible, free, and committed way” (Boni & Berjano, 2009: 206). They then argue that in order to achieve this aim, a set of conditions should be created that allows university students to acquire a set of values as ideals, reject the presence of an accumulation of opposing values and, above all, build their own set of values. This set of values ought to enable them to create personal criteria guided by the principles of justice and equality, as well as act coherently as a professional and citizen (Martínez et al. 2002, as cited in Boni & Berjano, 2009: 206). In this study, the proposal for ethical learning is reflected on particularly in the context of the European Higher Education Area (EHEA) and is illustrated through the description of experiences gained at the Technical University of Valencia in Spain, by academic staff and students of the engineering faculty. The study examines feedback from the participants concerning the implementation of ethical learning through three courses: ‘Industrial Sensors’ (a technical course) ‘Introduction to Development Aid’ and ‘Development Aid Projects’ (non-technical courses).

Results suggest that the humanities based courses are more effective to achieve ethical learning, as students who took these classes showed increased sensitivity towards the less privileged, compared to students who did not. This is interpreted to be indicative of a higher level of interest towards the subject of development, which arguably all engineers should critically reflect on in the work they do. The conclusions drawn in the study suggest that there is value and need to integrate broader soft skills alongside technical skills, as outcomes of engineering education, and it seems that there is great potential in achieving this through integrating humanistic subjects to help sharpen engineering students’ awareness of a diversity of development issues. This can be seen as an achievement of the sixth ethical dimension in the proposed model, namely: the development of one’s capacity for empathy and social perspective, which enables the student to have greater consideration for others and internalise values such as co-operation and solidarity.

A general concern raised by Boni and Berjano (2009) concerning both approaches to teaching ethical learning was the difficulty to academically evaluate the impact of the courses on students, and hence grade outcomes. A study that addresses questions of evaluating non-technical skills in engineering education is one by Fernandes et al. (2012). The study evaluated the impact of project-led education (PLE) on student learning processes and outcomes, particularly looking at students in their first semester of the first year of a five-year masters degree in engineering at the University of Minho, Portugal. As a consequence of the Bologna process, new methods of teaching and assessment have been developed which focus not only on the development of technical competences but also on transversal competences (Fernandes et al., 2012), which are exemplified by aptitudes for life-long learning, critical thinking and problem solving . The authors argue that teaching, learning, and assessment should be conceived in a way that provides students with numerous opportunities to support the development of such competences.

Findings from the study show that for some students, assessment in PLE focuses on deep-level learning and critical thinking because projects provide the opportunity to understand and link course content to real life situations (Fernandes et al., 2012). However, many students seem to still prefer traditional teaching and assessment methods in which they play a more passive role in the learning process (Fernandes et al., 2012). The findings also suggest that formative feedback plays an important role in PLE as it helped students recognise the utility and importance of feedback received during tutorials, group presentations and mid-term reports; which allowed them to improve their performance and set out new strategies for achieving the learning outcomes more effectively (Fernandes et al., 2012).

The downfall of PLE according to students, is the large workload and time needed to carry out the projects, which leaves the students feeling exhausted and not particularly rewarded for their hard work (Fernandes et al., 2012). In contrast to summative assessment where students felt that they put in hard work which is then reflected in good grades, such a correlation is not necessarily observable in PLE (Fernandes et al., 2012), but PLE might bear more weight from a human development perspective which is about more than measurable performance (e.g. good grades). The authors thus conclude that PLE assessment practices enhance deep understanding by linking theory to practice to solve real life problems, with feedback playing an important role as students are provided with opportunities to improve their work through discussing the results with their lecturers and tutors. A constraint of PLE identified in this study is the heavy workload and perceived low reward for tedious work (although results in a related study later showed above average results for PLE students versus students taught and assessed through more traditional methods). Fernandes et al. (2012) therefore conclude that more research needs to be done to understand and combine student and teaching staff perspectives of learning and assessment, and the interaction between them in practice.

The question of the role and importance of ethics for engineers and engineering activities is also addressed in the work of Keulartz, Schermer, Korthals, and Swierstra, (2004). Keulartz et al., (2004) argue that neither the vocabulary rooted in traditional philosophy nor applied ethics can adequately cope with the dynamic character of modern technological culture, because there is insufficient insight into the moral significance of technological artefacts and systems. According to Keulartz et al. (2004), technology studies (STS) can contribute to the ethical evaluation of technological development and that pragmatism can be a very useful tool in developing an ethical approach better equipped to deal with technology than applied ethics. In their paper, Keulartz et al. (2004) sought to develop a new perspective on the moral and social problems and conflicts that are typical for technological culture by bringing together insights from applied ethics, STS and pragmatist philosophy. The value of the argument brought forward in this article lies in its elucidation of the responsibility and accountability associated with technological advancements and innovations.

A transversal skill mentioned frequently in some of this literature is critical thinking (see Ahern et al., 2012; Boni & Berjano, 2009; Fernandes et al., 2012). For example, critical thinking in the university curriculum is explored by Ahern et al. (2012) particularly focusing on how it is defined, understood, taught, and evaluated. Critical thinking is a graduate attribute which is seen by academics as a particularly desirable outcome of student learning, and seen by many as the defining characteristic of a university education generally, but also for engineering graduates (Ahern et al., 2012). The evidence used to build the authors' argument is founded on a qualitative study that was conducted with academics at an Irish University in a variety of disciplines including engineering, where the aim was to examine how academics understood critical thinking. Questions concerning the differences in the importance of critical thinking across disciplines were addressed as well as suggestions for the identification of appropriate pedagogical techniques for introducing critical thinking skills to students. The data gathered also included document analysis of module descriptions and course work.

The results show that although definitions and understandings of critical thinking are broadly similar across various disciplines, there are significant differences in the formulation and articulation of the term (Ahern et al., 2012). Ahern et al. (2012) posit that academics from non-technical disciplines such as the humanities had very well formulated conceptions of critical thinking, whereas academics in engineering disciplines had clear ideas about the importance of critical thinking in engineering education, but had difficulty verbalising what it meant. The authors thus question how academics can explain critical thinking to students and encourage them to practice it, if they themselves are vague about its meaning and recognition.

The results also suggest that the secondary education of students fails to adequately lay the foundation for critical thinking, which passes over the task to universities (Ahern et al., 2012). Returning to the question of how critical thinking is understood and taught across disciplines, the authors argue that their evidence shows the following: 1) In engineering and other professional disciplines, critical thinking is not explicitly taught, although academics have the desire to do so. 2) In the humanities, a more concerted effort is made to ensure that critical thinking is addressed early on and explicitly in the curriculum and across modules (Ahern et al., 2012). Ahern et al. (2012: 128) define the critically thinking student as "one who can take the empirical and rise above this with abstraction and theory but can also use the concrete and context to ground their theory." They conclude that if universities claim to produce critical thinkers, they need to be more explicit about what it is and how it can be realised and assessed.

Although technical excellence is an essential attribute of engineering graduates, communication, ethical reasoning, societal and global contextual analysis skills, and understanding work strategies are also necessary capacities. Neglecting development in these areas, and teaching disciplinary technical subjects to the exclusion of a selection of humanities, economics, political science, language, and/or interdisciplinary technical subjects is not in the best interest of producing engineers able to communicate with the public, or engage in a global engineering marketplace, or trained to be lifelong learners (National Academy of Engineering, 2005). Education that neglects the development of non-technical skills such as 'cosmopolitan abilities' (Boni et al., 2012) and 'ethical learning' (Boni & Berjano, 2009) is not conducive for developing 'public-good professionals' (Walker, 2012) or public-good engineers, who orient their professional functionings to improving public services and capabilities for the poor. It is also counterproductive for the development of engineers who can orient their professional functionings to promoting sustainable development.

3.3.2 Improving engineers' dispositions towards sustainable development

According to Lucena and Schneider (2008: 252), sustainable development became a core theme around which engineering educators proposed new curricula in engineering ethics, economics and the academic field known as 'science, technology, and society'. Since the early 1990s, engineering activities dealing with humanitarian and community development activities have proliferated. Stimulated by the involvement of other professions in humanitarian relief, such as Doctors Without Borders (1971), Reporters Without Borders (1985), and Lawyers Without Borders (2000), engineers took up the challenge and independently organised a number of groups under some form of the name 'Engineers without Borders'. These groups include France's Ingénieurs Sans Frontières (late 1980s), Spain's Ingeniería Sin Fronteras (1991), Canada's Engineers Without Borders (2000), Belgium's Ingénieurs Assistance Internationale (2002), and others (Lucena & Schneider, 2008). In 2003 these groups organised 'Engineers Without Borders International' as a network to promote humanitarian engineering for a better world (Lucena & Schneider, 2008).

According to Lucena and Schneider (2008), engineering organisations in the early 21st century heeded the call to sustainable development and began taking action, ranging from hosting regional and world conferences to declaring their position with respect to sustainable development. Some organisations revisited their codes of ethics, and requested members to address these principles in their work, and other created international professional partnerships such as the World Engineering Partnership for Sustainable Development or the Federation of African Organisations of Engineers (1994). The general sentiment of advocates of ESD is that university leaders, faculty, and students should be empowered to catalyse and implement new paradigms by introducing sustainable development into all courses and curricula and throughout all other elements of higher education activities. Doing so, Lozano (2013:8) argues, would safeguard sustainable development as the 'Golden Thread' or 'Leitmotiv' throughout university systems. According to (Tilbury, 2011), education and learning for sustainable development refers to gaining of knowledge, values and theories associated with sustainable development, including learning to:

- Ask critical questions;
- Clarify one's own values;
- Learning to envision more positive and sustainable futures;
- Think systematically;

- Respond through applied learning; and
- Explore the dialectic between tradition and innovation (Tilbury, 2011).

Therefore engineering programs should graduate engineers who can design effective solutions to meet societal needs (Dym et al., 2005) and enable them, to become 'whole engineers' who are fully conscious of their roles in society and willing to use their agency to promote sustainable development. As mentioned before, there are many examples of ways in which universities are responding to calls for ESD, and literature on this topic is proliferating.

Across the literature, there are interesting lessons that can be drawn. For example, Carew and Mitchell (2008) argue that sustainable development should be taught as a contested concept. In their paper, they demonstrate that there is substantial variation in the way that individual engineering academics conceive of environmental, social and economic sustainability (Carew & Mitchell, 2008). In the study, a variety of sustainability themes and actions that were described by Australian engineering academics who participated in a professional development workshop that was documented for research purposes. The findings suggests that a significant part of the challenge for individual academics attempting to infuse concepts of sustainability into undergraduate coursework is to acknowledge that sustainability is a concept with both factual and value-based components, and therefore should and does/will manifest in diverse ways (Carew & Mitchell, 2008). Carew and Mitchell (2008) consequently suggest that rather than advocating specific tools, sets of actions or particular outcomes as 'sustainable', academics might develop approaches to teaching and learning that consider the role of values and assumptions in sustainability discourses.

A survey carried out by Azapagic, Perdan, and Shallcross (2005) suggests that, overall, the level of knowledge and understanding of sustainable development is not satisfactory and that much more work is needed in educating engineering students in this field. A total of 3134 students from 21 universities across Europe, North and South America, the Far East and Australia participated in the survey (Azapagic et al., 2005). While on average students appear to be relatively knowledgeable about environmental issues, it is apparent that significant knowledge gaps exist with respect to the other two (social and economic) dimensions of sustainable development (Azapagic et al., 2005). Also, students' awareness of sustainable development policy and standards was reported to be low (Azapagic et al., 2005). Azapagic et al. (2005) assert that the engineering students see sustainable development as important for them personally and even more important for them as engineers. Building on this finding, the authors argue that it should not be difficult to capture students' imagination by teaching sustainable development to make it as relevant to engineering as possible. This, Azapagic et al. (2005) argue, can be done through a series of lectures and tutorials on sustainable development, supplemented by practical examples and case studies integrated into the core modules of the engineering curriculum.

von Blottnitz, Case, and Fraser, (2015) demonstrate the feasibility of reforming core undergraduate engineering curricula to incorporate a focus on sustainable development, from the first year of study onwards. Their paper reports on a curriculum reform process in chemical engineering at a South African university. Departing from traditional curricula, the new first year course incorporates a 'natural foundations' strand that introduces nature not just as a resource, or as imposing parameters on engineering dexterity, but also as 'mentor and model' (von Blottnitz et al., 2015). Sustainability problems are interpreted as systematic violations of nature's grand cycles and contrasted with development needs, particularly in relation to provision of water and energy (von Blottnitz et al., 2015) . It is reported that by the end of the course most students rated their knowledge of environmental and sustainability issues as good or excellent. The authors cite the significant achievement of this new programme as the interweaving of sustainable development in a mainstream undergraduate engineering curriculum, and predict such an approach may become a trend in chemical engineering programmes.

However, as De La Harpe and Thomas's (2009) investigation indicates, there is no single approach or formula for implementing ESD curriculum change that has been found to be effective, and bringing about such change is difficult. Nevertheless, several conditions can provide a starting point to guide people involved in planning change and introduction of ESD. De La Harpe and Thomas (2009: 83) state, "We would be more than halfway there if we can ensure that time in such efforts is spent on getting a critical mass of people on board to form a group to lead, champion and implement change." They also state that it is necessary to develop a vision and a clear plan, and to ensure that there are sufficient resources and staff development opportunities available to achieve that vision.

3.4 Gender and engineering

According to Fuchs (1997), the history of engineering occupations shows that they have evolved exclusively on the basis of men's experiences. The dualism of rational/irrational and its relationship with masculinity and femininity has functioned as a process of including men in and excluding women from the fields of technology and engineering for a long time

(Holth, 2014). Holth (2014) argues that individuals, life stories, and everyday practices that deviate from this stereotypical division pave the way for more diversified perceptions of the gender practices performed in engineering, when women and men choose a career in engineering (Holth, 2014). The empirical data for Holth's (2014) study consists of the life stories of 46 computer and mechanical engineers; 26 of whom are women and 20 men. The findings show that there are significant differences between the gender stereotypes of the engineer, and engineers in reality, and that the ideology of 'rational men' and 'irrational women' in engineering is mistaken (Holth, 2014). The findings also imply that neither gender nor technology is a constant or a given, but that it should continuously be reinterpreted.

Masculinities and femininities are set up as opposites and mutually exclusive and they can be exemplified in the technological/social dichotomy and in the idea that women are socially inclined and hence non-technical, while men are technically inclined and therefore seen as non-social (see Faulkner, 2007, 2009). This is a part of the cultural distinction between women's presumed emotionality and men's presumed instrumentality (Holth, 2014). Thus conceived, technical competence is constructed as a part of what it means to be a man, and of masculinity, and in the process, women and femininity have been constructed as non-technical (Faulkner, 2007, 2009, 2010).

Technological artefacts have also mainly been associated with men and seen as part of masculine identities. Artefacts traditionally associated with women, e.g. the sewing machine, have not achieved, unlike their male encoded counterparts, the status of 'real technology' as they belonged to the domestic sphere and hence were valued less than the technology used in public sphere production by men (Holth, 2014). Likewise, technical artefacts have been categorised as 'hard' and 'soft' and associated with different stereotypical modes of thinking (Holth, 2014). The hard masculine mode of thinking is symbolically associated with emotional distance, objective rationality, and abstract reductionist problem solving, while the gendered stereotypical view of women as emotional and irrational has been deemed incompatible with technological development and has contributed to women's exclusion from the technological sphere (Holth, 2014). Rational intellectual thinking and abstract reasoning have therefore symbolically formed the ideal of the engineer as a knowledge seeking individual, described in terms of a collected, calculating, and rational *man* (Holth, 2014).

A study by Faulkner (2007) draws on ethnographic fieldwork in two UK offices of a building design engineering consulting company, where data collection methods involved jobshadowing six engineers over the course of 5 weeks (Faulkner, 2007). Findings discussed include that 'technicist' engineering identities are as strong as they are partly because they converge with available masculinities in at least two important ways: they evoke a sense of hands-on 'nuts and bolts' work (even though engineers rarely do this themselves); and they make engineers feel powerful (i.e. they make things e.g. buildings, machines, cars that 'work'). Thus, many men engineers cleave to a technicist engineering identity because it feels consistent with versions of masculinity with which they are comfortable.

While most women engineers also take pleasure in and identify with the material power of the technologies they build or use, the majority nonetheless identify more readily with the science base of engineering than with hands-on engineering (Faulkner, 2007). So, the traditional association of men with engineering tools still marks professional engineering as masculine and makes the 'nuts and bolts' identity feel 'manly' (Faulkner, 2007).

The tendency to see 'the technical' and 'the social' as mutually exclusive reinforces some men's resistance to embracing a heterogeneous engineering identity (Faulkner, 2007). Although a growing proportion of the men now entering engineering do not come from a technicist background, and although some women opt for hands-on work, still considerably more men than women engineers have been socialized into a hands-on relationship with technology. As women engineers testify, this can seriously undermine their confidence and their sense of belonging, especially when they first enter engineering degrees (Faulkner, 2007).

A study by Beddoes (2012) examines the current state of feminism in the emerging field of engineering education and identifies barriers, challenges, and tensions experienced by scholars and educators who have been involved with feminist engineering education initiatives. Using data from 15 in-depth interviews, she identifies a number of changes that would facilitate deeper engagement with feminism in engineering education research. These changes include that engineering education researchers should stop: asking how to change women; using men as the unacknowledged reference point; and conflating gender and sex (Beddoes, 2012). Another problem that gets in the way of good engineering education research is the classic stereotype of the engineer as a man who is brilliant at, and passionate about, technology but not so good at interacting with people (Faulkner, 2010). This image not only says 'technology is for men', it also says being 'into technology' means not being 'into people' (Faulkner, 2010). As women are stereotypically 'into people', the image carries the implicit message that women engineers are not 'real women', or perhaps not 'real engineers' (Faulkner, 2010: 68).

3.6 Summative discussion

Several issues of concern were identified in this body of literature. Firstly, measures to improve engineering graduates' soft and transversal skills or their dispositions towards sustainable development, will fall short of developing all students into agents of sustainable human development if they remain offered as elective subjects (which is usually the case; see Karatzoglou, 2013; Lozano, 2013).

Secondly, most engineering education reform efforts appear as ad hoc, fragmented institutional attempts to broaden outcomes, often based on measures that lack empirical evidence of their long-term effectiveness. That is, there is lack of longitudinal empirical evidence showing which courses are most effective in imparting the kind of knowledge required for sustainable engineering. There are studies that discuss engineering students' understanding and evaluations of 'sustainable development' courses (for example, see Boni et al., 2012; Case & Marshall, 2015; Connor et al., 2014; Fernandes et al., 2012; Segalás et al., 2010; von Blottnitz, et al., 2015; von Blottnitz, Case, Heydenrych, & Fraser, 2013). However, most studies do not go as far as evaluating the *long-term* effect of these courses on students' professional functionings, nor do they assess the long term-term results of the reform measures or new courses they propose for their education institutions. This shows that there is gap in engineering education literature, which needs to be filled.

Thirdly, when it comes to teaching sustainable development, most attention appears to be focused on engineering curriculum change, and fewer studies make considerations about how integrated engineering pedagogies could make a positive contribution to reform efforts. Those that do have reported failure to address sustainable development through engineering pedagogy due to lecturers' ambiguity on the concept and confusion about how they can infuse related issues in their actual teaching (Carew & Mitchell, 2008; Jones et al., 2008). That is, there appears to be a gap in engineering education literature concerning how sustainable development principles can be infused in the actual teaching practices of engineering educators (regardless of the course they teach).

The concerns identified in this review of literature influenced my thinking on the type of questions that ought to be asked during interviews to better understand the effect of measures to broaden engineering education outcomes. As opposed to only asking engineering students if they find humanities-based elective courses useful, I decided to explore what valued capabilities and functionings are enhanced because of taking the courses. Instead of only asking how their awareness and commitment to sustainable development might have improved, I would seek to understand what they value about knowledge on sustainability, and how they see their potential to exercise their professional agency to promote it.

Furthermore, knowing more about the impact of these courses on engineering graduates requires researching graduates' professional progress (although this is beyond the scope of this thesis) to see if they are practicing their jobs in ways that can be considered as enhancing sustainable human development, even if it is only in incremental ways.

For the lecturers, it would be important to ask questions that stimulate their thoughts on how they might personally employ alternative pedagogies, irrespective of the courses they teach, to promote students' critical thinking. The gaps identified in this review of literature also reinforced the decision to employ the capability approach.

Finally, and perhaps most importantly, it seems that there is a lack of a clear and comprehensive conceptual frame or practical guidelines that are being employed as a normative and evaluative framework for engineering education reform efforts in general (Karatzoglou, 2013). In different ways, this study aims to contribute to and build on engineering education literature, and ESD literature. It is hoped this thesis can make a unique conceptual and empirical contribution to existing ESD literature by offering a study that uses a capabilities lens on engineering education, sustainability, and development and integrates this with qualitative data comprising of combined global North, and global perspectives.

Chapter 4

The capability approach and higher education research

4.1 A capabilities lens on education

As outlined in chapter 1, the way we view education is challenged when we look at development primarily in terms of capabilities expansion, instead of only in economic terms (Ribeiro, 2015). That is, the human being is placed at the centre of concerns, and sustainable and human development is presented in terms of enlarging individuals' choices (United Nations Development Programme, 1990). However, as pointed out by Wood and Deprez (2012), Sen (1999) is clear in depicting education as having both intrinsic value for individuals *and* social value for communities. In addition, as Nussbaum asserts, the capability approach is not a theory of human nature that is merely focused on individuals, but it is evaluative and ethical from the start. For example, questions that can stimulate our thinking about the type of world we want to live in include: 'Among the many things human beings might develop the capacity to do, which ones are the valuable ones? Which are the ones that a minimally just society will endeavour to nurture and support?' (Nussbaum, 2011: 28). Applied to engineering education, we might then ask: Among the many things that future engineers might develop the capacity to do, which are the important ones for public-good engineering? Which are the most relevant for sustainable human development? Moreover, which are the ones that engineering education should endeavour to nurture and support?

A capabilities view on engineering education inspires the goal to judge educational practices according to how they enhance individual well-being for each student, whether the classroom community is a context for mutual well-being (Wood & Deprez, 2012), and whether individual students' capabilities can be used to widen capabilities in society. It is therefore, clear that the role of engineering education as regards the capability approach is multiple and complex (Ribeiro, 2015). That is, from a capabilities perspective, engineering education should strive to widen opportunities 'to be and to do' for students, 'both in the spirit of individual enhancement and its impact on and influence of social enhancement' (Wood & Deprez, 2012: 477). Therefore, capabilities regarding education operate on three levels: 1) the opportunity for individuals to participate in education; 2) the effective freedoms gained through education for the individual (Vaughan, 2007); and, 3) the effective freedoms gained through education for wider society. This implies that the responsibility of professional educators is correspondingly threefold: 1) to ensure that students can fully participate in learning experiences; 2) to ensure that they have opportunities to discern what they need to realise functionings they value (Wood & Deprez, 2012); and 3) to help ensure that valued functionings are reasonably aligned with the objective to enhance valuable capabilities in society.

Thus conceived, education is a capability in itself and it is foundational to other capabilities (Sen, 2002; Terzi, 2007; Unterhalter, 2002). Considering some implications of a capabilities lens on education, this chapter builds on chapter 1 but now particularly shows how emerging ideas from the capability approach might inform a theoretical framework for engineering education geared towards sustainable human development. More specifically, four dimensions of education are discussed: namely, education as: 1) a capability, 2) an instrument of social justice, 3) a foundation for agency and resilience, 4) a basis for sustainable human development. Using this as a basis for theorizing the potential of universities to cultivate public-good engineers, the chapter also discusses the application of the capability approach to higher education research and describes the process of developing ideal-theoretical lists of educational capabilities. The chapter ends with a preliminary framework of educational capabilities for public-good engineering.

4.1.1 Education as a capability

According to Sen (2002), Terzi (2007) and Unterhalter (2002), the capability to be educated is basic in the sense of being a fundamental freedom, and foundational to other freedoms as well as future ones. Terzi (2007) provides the example of the opportunity to learn mathematics. She argues that formally learning mathematics not only expands the individual's various functionings related to mathematical reasoning and problem solving, but it also widens the individual's sets of opportunities (Terzi, 2007). On the one hand, Terzi (2007) agues, more complex capabilities are enabled (for example, applying mathematical knowledge to algebra, geometry, or calculus). On the other hand, better prospects for opportunities in life are enabled (Terzi, 2007) (for example, having broader career options in mathematics related occupations such as accounting, actuarial sciences, and engineering).

Therefore, the broadening of capabilities enabled by education extends to the advancement of complex capabilities, by promoting reflection, understanding, information, and awareness of one's capabilities (Terzi, 2007). At the same time, education promotes opportunities to formulate a range of beings and doings that individuals have reason to value (Terzi, 2007;

also see Saito, 2003). Furthermore, the expansion of capabilities entailed by education extends to varieties of occupations and certain levels of social, civic, and political participation (Terzi, 2007). Thinking of education in the above meaning relates substantially to an understanding of education as ‘a complex good entailing instrumental and intrinsic values’ (Terzi, 2007: 31; also see Saito, 2003). As such, providing access to education and promoting a concrete set of basic learning outcomes, such as reading and writing (Unterhalter, 2002), creates opportunities for other, more sophisticated beings and doings such as being knowledgeable about the challenges of sustainable development.

However, from a capabilities viewpoint, it can be argued that learning that stops at the level of providing only basic reading and writing is insufficient to advance sustainable development in its full sense (Ribeiro, 2015). In the case of engineers, it can similarly be argued that education that stops at the level of providing technical expertise and basic understandings of the concept of sustainable development is inadequate to advance sustainable human development to the fullest extent possible. That is, engineering education should manifest as an opportunity for students to learn how they can advance sustainable human development. In order for this happen, engineering students need not only to gain engineering expertise, but also to learn to value principles of social justice and recognise the inherent potential of engineers to contribute to development that is just.

4.1.2 Education as an instrument of social justice

According to Oosterlaken (2009), adopting the capability approach immediately seems to be strongly compatible with recognizing and improving the contribution of technology and engineering products to development. After all, Oosterlaken asks, what is technology for, if not for increasing human capabilities? (Oosterlaken, 2009). Just as the invention of the wheel enhanced our opportunities to transport heavy loads; more recently, the computer enhanced our chances to make complex calculations (Oosterlaken, 2009). This reflects how technologies have grown more complex over time, and how they are (in an increasingly complex way) intertwined with society, institutions, laws, and procedures (Oosterlaken, 2009). Additionally, technological advancement intends to add to our capabilities to survive (such as in the case of medical equipment), or to participate in public deliberation (such as in the case of internet applications that facilitate political discussion) (Oosterlaken, 2009). As obvious as making this connection between technology and capabilities may seem, philosophers working on the capability approach so far do not seem to have thoroughly realized the relevance of technology, engineering, and design for capability expansion (Oosterlaken, 2009).

It is important to note that philosophers and sociologists of technology have argued in the past decades that engineering products are far from being neutral tools to be used at will for either good or bad (Oosterlaken, 2009). Rather, they are value-laden and thus inherently normative (Oosterlaken, 2009). Based on this point of view, values such as sustainable human development and social justice have great potential to be realized through technology, if professional engineering functionings are unequivocally aligned with them. This means that the 'details of design are morally significant' (Oosterlaken, 2009: 95). Therefore, if technologies are value-laden, engineers should be conscious of this and design technologies in such a way that incorporates their moral values, and they should not too easily assume that a certain product or technology will do well in expanding people's capabilities (Oosterlaken, 2009). As such, if the capability approach is applied to the design of new technologies and products, the most important objective for engineering might be to use 'capability sensitive design'(Oosterlaken, 2009: 96) and engineering knowledge to advance social justice.

As Oosterlaken (2009) states, capability sensitive design is not something completely new or entirely different from what Nieusma (2004) calls 'alternative design scholarship'; there are significant synergies as is evident from the explanation which follows. Design scholars from diverse fields have attempted to assist marginalized social groups by redirecting design thinking toward their needs (Nieusma, 2004). By offering different options to dominant design activities, alternative design scholarship seeks to understand how unequal power relations are embodied in, and result from, conventional design practice and products (Nieusma, 2004). That is, alternative design scholars analyse how technologies and other engineered artefacts are implicated in larger social problems such as rampant consumerism, ecological abuse, and restricted access to the built environment (Nieusma, 2004). As such, alternative design scholarship offers designers and engineers (and other professional groups at the forefront of development work) an opportunity to rethink how their work might be applied as wisely and as fairly as possible (Nieusma, 2004).

In agreement with Oosterlaken (2009), there is a clear link between capability sensitive design, universal design (see Goldsmith, 2000) and participatory design (see Bratteteig & Wagner, 2014 or Schuler & Namioka, 1993) methodologies. Universal design is founded on the assumption that it is possible to design objects and spaces such that they are usable (and will be used) by a vast range of the population, including but not limited to people with disabilities (Connell & Sanford, 1999; Goldsmith, 2000; Nieusma, 2004). Universal design theorists prompt designers to think systematically about inclusion and to broaden their notions about who the users are (Nieusma, 2004). Referring back to arguments made in chapter 1, some engineering products (like luxury cars) expand capabilities for the rich, instead of broadening capabilities for poor and marginalised communities. By virtue of the steep price attached to such products, poor and marginalised groups in society are often systematically, but unnecessarily impeded in their access to certain means of transport. Thus conceived, some engineering outcomes, by design, further alienate poor and marginalised communities from certain capabilities. Universal design insights have been influential in challenging such narrow approaches to product design. By so doing, universal design scholarship contributes to analyses of social power in design by: 1) Identifying groups of people whose needs systematically go unmet, and 2) Advocating that the design community should consider the needs of such people much more seriously (Nieusma, 2004).

From its inception, participatory design scholarship has sought to cope with differences of perspective and goals in an explicit, productive, and fair way (Bratteteig & Wagner, 2014; Nieusma, 2004). Instead of ignoring the fact that conflicting interests underlie many important design decisions, participatory designers attempt to leverage such differences to arrive at outcomes suitable to diverse interests (Nieusma, 2004). Participatory design scholars call attention to underlying inequalities, and provide two core reasons for working against them: participatory decision making is fairer and more intelligent than non-participatory processes (Nieusma, 2004). It is fairer because people who are affected by a decision or event should have an opportunity to influence it, and it is more intelligent because broad participation informed by multiple interests is more likely to result in widely agreeable solutions to shared problems (Nieusma, 2004).

It is thus clear that principles embedded in universal and participatory design are consistent with ideals of social justice. While universal design is concerned with widening the use and accessibility of social artefacts and the built environment to marginalised populations, participatory design aims at making design processes more inclusive and hence beneficial to the end user. In this way, participatory design is aligned with the concept of public deliberation, the importance of which is emphasised in the capability approach. Capability sensitive design can therefore be described as an extension of these objectives, because it prompts questions surrounding the effective opportunities and functionings enlarged by design outcomes. More specifically, it advocates for more attention to be paid towards the capabilities of people living in poverty. This indicates that capability sensitive design is able to integrate lessons from existing fields of scholarship, into a more comprehensive approach that offers a clear philosophical foundation of the ultimate ends of design (Oosterlaken, 2009). Most importantly, capability sensitive design can provide engineers with the inspiration to orient engineering design towards social justice.

Once engineering students are equipped with knowledge that enables critical awareness of the interconnectedness of engineering, design, and broader objectives of social justice, they need to be encouraged to take action that advances it. That is, once engineering students recognise that engineering knowledge can be placed at the service of social justice, they need to develop the autonomy and agency to translate this possibility into reality, through their professional functionings (both individually and collectively). Therefore, engineering education ought to develop and heighten students' agency and resilience. This is particularly important because of existing economic, political, and environmental constraints (or conversion factors) that make engineering activities complex and challenging.

4.1.3 Education as a foundation for agency

According to Lozano, Bonni, Peris, and Hueso (2012), the concept of agency (discussed in chapter 1) is particularly relevant for reflecting on education as it implies three levels of claims, namely the claims that it is possible to:

1. Educate people to apply reason to personal decisions and preferences,
2. Enhance people's capacities to reflect critically on the world and to envisage desirable changes, and
3. Cultivate the capacities to accomplish such changes in practice.

That is, for the capability approach, the goal of education is also to expand people's agency; to enable them to be the authors of their own lives (Lozano et al., 2012). Therefore, without an authentic opportunity to be educated or the means to avail oneself of that opportunity, many people may be limited to constrained agency and freedom (Wood & Deprez, 2012). If higher education experiences are to aid students in being and acting in ways that they value, they ought to create opportunities for authentic autonomy and choice in terms of how and what students learn, and in terms of how they demonstrate their learning (Wood & Deprez, 2012). Moreover, students need opportunities to develop 'authentic and expressive voices' (Wood & Deprez, 2012: 479). In addition, in order to exercise their voices and choices well, students need to develop critical capacities in order to recognize how conventional cultural assumptions have shaped their perceptions, attitudes and values (Wood & Deprez, 2012). Ideally, in the process of encountering relevant topics (such as sustainable development in engineering education), lecture halls should be spaces that are conducive for critical, dialogic, and inquiring exchanges (Wood & Deprez, 2012). Wood and Deprez (2012: 479) refer here to a context that: provokes students' views on a variety of course topics; 'scaffolds their reasoning and reflection as they sift through differing opinions and arguments', and promotes balanced judgment of opposing points of view or respectful critiques. Furthermore, because student agency is a fundamental dimension of human well-being (see Walker & Unterhalter, 2007), higher education needs to provide the conditions for students' agency to develop (Wood & Deprez, 2012).

As asserted by Walker (2006), a lack of agency or constrained agency equates to disadvantage, and it is therefore essential to decide what capabilities support agency development in higher education (Walker, 2006). In the case of cultivating public-good engineers, we therefore need to consider the ways in which engineering education as an opportunity and as a process develops agency in learners. Drawing from Walker's (2006) discussion on the assessment of pedagogic quality in higher education from a capabilities perspective, we could argue that if agency is being disabled in engineering education, then engineering education is diminished and its quality undermined. This is because failing to develop agentic engineers, is failing to maximise the potential for engineering knowledge to be used *for* social justice. If this is the case, then the potential for developing engineers who are agents of sustainable human development is decreased.

4.1.4 Education as a basis for sustainable human development

To enhance development fully as expressed in the capability approach, education must move towards specifically addressing the needs and aspirations of individual students, their ability to think, reason, and build up self-respect, as well as respect for others (Ribeiro, 2015). According to Ribeiro (2015), the importance of such mental power (i.e. cognitive, emotional, and social abilities) is making its way into education policies often under the name of 'life skills'. Life skills education has gradually come to be seen as a comprehensive approach to education of good quality. Specific teaching methodologies for mental skills development based on participation, interaction and the use of learning friendly environments have been developed and extensively used for teaching and learning life skills (Ribeiro, 2015). By focusing on the methodology, the approach can be adapted to address specifically, multiple values, attitudes and behaviours regarding a number of different topics, including environmental protection, gender issues, human rights approaches, and the promotion of tolerance and peace building (Ribeiro, 2015). The large number of specific abilities has been grouped under three overarching categories by the WHO (see WHO, 2004). These categories relate to: 1) problem-solving skills; 2) autonomy and a sense of purpose and 3) social ability.

Furthermore, the capacities that fall into these categories are directly in line with characteristics and abilities identified as constituting resilience among young people (Ribeiro, 2015). Ribeiro (2015) convincingly argues that an educational framework for life skills can be seen as a basis for ESD. She grounds her proposal in the life skills framework for 'teaching, learning, and human development' recommended in the report to UNESCO by the International Commission on Education for the 21st Century (see UNESCO, 2005). According to Ribeiro (2015), the framework consists of four pillars of learning that combine the three categories of life skills (described previously) with technical skills in a teaching and learning situation. These four pillars are: 1) learning to know, 2) learning to be, 3) learning to live together and 4) learning to do:

- Learning to know refers to the understanding and use of knowledge, where related abilities include critical thinking, problem solving, and decision-making life skills that are fundamental to informed action.
- Learning to be concerns the concept of agency, which includes life skills for coping, self-awareness, esteem, and confidence, whilst aiming at building an identity, valuing oneself, setting goals, etc.
- Learning to live together implies feeling affiliated to a group, a category, a society, or culture, and understanding and respecting differences. Related interpersonal abilities include communication and negotiation life skills that are essential to define a person as a social being in constant interaction with the world.
- Learning to do is linked to the mastering of cultural tools (i.e. patterns of behaviour) in order to act. Related abilities are associated with the practical or technical application of what is learned (Ribeiro, 2015).

This account of life skills underscores that actions are influenced not only by knowledge but by perceptions, values and attitudes that affect one's decision to act (one's agency) in a particular way. As Ribeiro (2015) explains, learning to be and to live together underlines the importance of interaction between internal and external factors. The internal factors refer to theories that reality for each person is defined by him or herself, which is directly linked to the notion of agency in the capability approach (Ribeiro, 2015). Amongst other things, this involves seeing oneself as the main actor in defining a positive outcome. External factors refer to the need to recognize the impact of external pressure, the need for continuous social support, and the viewing of collective well-being as a prerequisite to individual well-being (Ribeiro, 2015). This is not dissimilar from Nussbaum's (2000) notion of internal, external and combined capabilities, with the last being what we should aim for, even though Nussbaum offers no definite concept of agency seeing agency subsumed into well-being (see Nussbaum 2011).

Ribeiro (2015) therefore argues that education for sustainable human development must be an education that aims to help people of all ages understand the world in which they live better, and better to act on this understanding. It needs to address the complexity and interconnectedness of problems such as poverty, environmental degradation, human rights, etc. (Ribeiro, 2015). And these topics should be addressed not only by providing information, but also the abilities needed to understand and use this information to establish agency and hence action that leads to sustainable development (UNESCO, 2005).

Ribeiro (2015) illustrates how a life skills framework can be used to group Nussbaum's (2000) central human capabilities (see table below), arguing that education needs to take into account the inter-relatedness of teaching, learning, and human development. Through education, people need to be assisted in developing abilities that help them think critically and creatively, solve problems, make informed decisions, cope with and manage new situations, and communicate effectively (Ribeiro, 2015). That is, higher education should be of such quality that it leads to specific learning outcomes in the form of valuable capabilities (Ribeiro, 2015). This sentiment is echoed in many studies that have applied the capability approach to conceptualise more socially just outcomes of teaching and learning in higher education (as discussed in chapter 3).

To conclude, this section has shown how a capabilities lens on education can highlight dimensions (or instrumental and intrinsic values) of education that may otherwise be overlooked if human development is not placed at the centre of higher education objectives. Although other theoretical lenses (e.g. Margaret Archer's Social Realist Theory) are useful for researching student learning in engineering (see Case, 2013) or investigating issues of engineering curriculum design (see Case, 2011), looking at engineering education from a capabilities perspective prompts us to focus a critical eye on outcomes of development, engineering, and education more broadly.

Table 2: Links between ESD, the capability approach and central human capabilities

ESD provides skills for:	The capability approach covers:	Central human capabilities include:
Learning to know	Reasoning	Practical Reason
Learning to be	Agency	Senses, Imagination and Thought, Play
Learning to do	Achieved functionings	Life, Bodily Health, Bodily Integrity, Control of One's Environment.
Learning to live together	Collective agency and collective well-being	Affiliation, Emotions, Other species

Source: Author's own; adapted from Ribeiro (2015).

4.2 Developing ideal-theoretical lists for educational capabilities

Given the aim of theoretically determining categories of capabilities fundamental to the capability to be educated for public-good engineering, a certain ideal, general level of specification is appropriate.

The selection of capabilities, or 'dimensions' ought to be multi-dimensional, the dimensions should be incommensurable, and one cannot be reduced to any of the other dimensions (Alkire, 2002, 2010; Nussbaum, 2003; Robeyns, 2005; Terzi, 2007; Walker, 2006). This is important to note because each dimension supports the others, and all are important (Walker, 2006). Thus conceived, it is clear that putting specific content into capabilities (through selecting a list), is a complex task. Robeyns (2003: 70-71) suggests five criteria for the selection of capabilities:

1. 'Explicit formulation', refers to the idea that any list should be 'explicit, discussed and defended'.

2. ‘Methodological justification’ involves clarifying and scrutinizing the method that has generated the list and justifying its appropriateness.
3. ‘Sensitivity to context’ means taking into account audience and situation, speaking ‘the language of the debate’, and avoiding ‘jargon’ which might alienate prospective groups. In some contexts therefore, the list might be more abstract or theory-laden than in others.
4. ‘Different levels of generality’ applies to lists that are to be implemented. This involves drawing up a list in two stages, where the first stage involves an ‘ideal’ list and the second a more ‘pragmatic’, second-best list, taking actual constraints into account.
5. ‘Exhaustion and non-reduction’ requires that the listed capabilities should include all the important elements and the elements should not be reducible to each other (although there may be some overlap). For example, one would not list respect and recognition as separate capabilities but as elements of the same capability.

These criteria for selecting relevant functionings and capabilities (in education in this case) provide a methodological basis upon which to proceed to one of the tasks of this thesis: determining what subsets of enabling conditions are fundamental to capabilities for public-good engineering. Drawing from questions asked about the relationship between capabilities and higher education (see Walker, 2006), what we need to ask in the case of engineering education that is for sustainable human development (or public-good engineering) is:

- Does anything count as engineering education? If not, how do we judge which students in engineering education are lacking capabilities central to public-good engineering?
- Should we then produce a list, or lists, in order to indicate the content to a norm social justice in engineering education?
- In addition, should we try to work out what such engineering education might look like, and then consider how practice and reality are congruent with our view of justice?

These questions illustrate that if we are concerned about engineering education and its contribution to sustainable human development, we need some idea of what we take to count as ‘engineering education’. While at some abstract philosophical or theoretical level one might argue that all capabilities valued by engineers matter, it can also be argued that there are some capabilities that matter more than others do because of their relevance for sustainable human development. Considering this, what capabilities matter most for public-good engineering?

A starting point to address this question is the development of an 'ideal-theoretical list' of educational capabilities (Walker, 2006; Wilson-Strydom, 2014). As Walker (2006) asserts, such a list need not be strictly generated through public participation (and is limited in this respect), but making it public is to invite participatory dialogue (Walker, 2006). In her argument that there is a valid case for ideal theoretical lists of educational capabilities Walker (2006) states that such lists should be for a particular purpose, evaluation, or critique. They also should not be fixed, canonical, or hierarchically ordered, and they should include participation and dialogue in some way (Walker, 2006). The idea, Walker (2006) argues, is for higher education communities to produce their own flexible, revisable, and general list in a participatory manner, but not one definite list of higher education capabilities for all contexts. Walker (2006) also asserts that a working list provides content to what we take to count as 'higher education' and it addresses the case for a theoretical understanding of the human good. Several authors have developed ideal theoretical lists for educational capabilities that are worth specific mention. Therefore, before providing my ideal-theoretical list of 'educational capabilities for public-good engineering', I briefly summarise the outcomes of similar scholarly endeavours in order to then highlight what is different about mine.

4.3.1 Terzi's basic capabilities for educational functioning

Terzi's (2007) work is concerned with identifying a subgroup of enabling circumstances that are fundamental to the capability to be educated. Terzi (2007) asserts that selecting basic capabilities in education is a complex task, and she stresses that her account of this aspect aims necessarily at indicating some possible developments, rather than at providing a complete and exhaustive account. For Terzi (2007), selecting basic capabilities in education means looking at what beings and doings are at the same time crucial to meeting basic needs, whilst being foundational to the enhancement of other beings and doings, both in education and for other capabilities. As such, Terzi's (2007) aim is to provide a normative account of enabling conditions whose absence would put the individual student at a considerable disadvantage. At the same time, Terzi (2007) states, the focus is on enabling conditions whose exercise is particularly important in childhood. Terzi (2007) asks, 'What are, ultimately, the enabling conditions constitutive of the basic capability to be educated? She suggests the following list of basic capabilities for educational functionings: 1) Literacy, 2) Numeracy, 3) Sociality and participation, 4) Learning dispositions, 5) Physical activities, 6) Science and technology, 7) and 8) Practical reason (Terzi, 2007: 37; see table 3 below for summary).

Table 3: Terzi's basic capabilities for education functioning

Capability	Description
Literacy	Being able to read and to write, to use language, and discursive reasoning functionings
Numeracy	Being able to count, to measure, to solve mathematical questions, and to use logical reasoning functionings
Sociality and participation	Being able to establish positive relationships with others and to participate in social activities without shame
Learning dispositions	Being able to concentrate, to pursue interests, to accomplish tasks, to enquire
Physical activities	Being able to exercise and being able to engage in sports activities
Science and technology	Being able to understand natural phenomena, being knowledgeable on technology, and being able to use technological tools
Practical reason	Being able to relate means and ends and being able to critically reflect on one’s and others’ actions

Source: Author’s own; adapted from Terzi (2007).

4.3.2 Walker’s basic capabilities for higher education

Walker (2006) proposes an ideal-theoretical list of educational capabilities that is not over-specified or too prescriptive, and pays attention to student voices and to capability scholars. Considering that capabilities theorists focus on human development as a whole, education is referred to in very broad terms (Walker, 2006). Effectively, Walker’s (2006: 111) purpose is to: “provoke dialogue amongst practitioners, managers, leaders and students about what we take to be ‘quality’ in standards of teaching and learning in universities, and genuinely educative (good) experiences of higher education”. One of the questions guiding Walker’s selection of educational capabilities is, “What might higher education pedagogies, for example, look like, if they adopted a capabilities framework for evaluating the quality of learning and teaching?” (Walker, 2006: 111). In response, she argues that the following capabilities should be central to any higher education process that seeks to enhance humanity, effective agency and well-being: 1) Practical reason, 2) Educational resilience, 3) Knowledge and imagination, 4) Learning disposition, 5) Social relations and social networks, 6) Respect, dignity and recognition, 7) Emotional integrity, and 8) Bodily integrity (Walker, 2006: 127-128). A more detailed description of these capabilities is provided in the table below.

Table 4: Walker's capabilities for higher education

Capabilities	Descriptions
Practical reason	Being able to make well-reasoned, informed, critical, independent, intellectually acute, socially responsible, and reflective choices. Being able to construct a personal life project in an uncertain world. Having good judgement.
Educational resilience	Able to navigate study, work and life. Able to negotiate risk, to persevere academically, to be responsive to educational opportunities and adaptive to constraints. Self-reliant. Having aspirations and hopes for a good future.
Knowledge and imagination	Being able to gain knowledge of a chosen subject (disciplinary and/or professional) its form of academic inquiry and standards. Being able to use critical thinking and imagination to comprehend the perspectives of multiple others and to form impartial judgements. Being able to debate complex issues. Being able to acquire knowledge for pleasure and personal development, for career and economic opportunities, for political, cultural and social action and participation in the world. Awareness of ethical debates and moral issues. Open-mindedness. Knowledge to understand science and technology in public policy.

Capabilities	Descriptions
Learning disposition	Being able to have curiosity and a desire for learning. Having confidence in one's ability to learn. Being an active inquirer
Social relations and social networks	Being able to participate in a group for learning, working with others to solve problems and tasks. Being able to work with others to form effective or good groups for collaborative and participatory learning. Being able to form networks of friendship and belonging for learning support and leisure. Mutual trust.
Respect, dignity and recognition	Being able to have respect for oneself and for and from others, being treated with dignity, not being diminished or devalued because of one's gender, social class, religion or race, valuing other languages, other religions and spiritual practices and human diversity. Being able to show empathy, compassion, fairness and generosity, listening to and considering other person's points of view in dialogue and debate. Being able to act inclusively and being able to respond to human need. Having competence in inter-cultural communication. Having a voice to participate effectively in learning; a voice to speak out, to debate and persuade; to be able to listen.
Emotional integrity, emotions	Not being subject to anxiety or fear which diminishes learning. Being able to develop emotions for imagination, understanding, empathy, awareness and discernment.
Bodily integrity	Safety and freedom from all forms of physical and verbal harassment in the higher education environment.

Source: Author's own; adapted from Walker (2006).

4.3.3 Wilson-Strydom's capabilities for university readiness

Wilson-Strydom (2015a) carried out a comprehensive review of access, readiness, and transitions literatures, and of capabilities theory and its applications in higher education research as a foundation for her proposed theoretical list. This list, Wilson-Strydom (2015a) argues, highlights the multi-dimensional nature and the complexity of transitioning[29] to university, and shows what students ought to be able to be and do as they enter university. Wilson-Strydom (2015a) proposes that opportunities to develop certain capabilities of university readiness should be created intentionally during students' transition into higher education (i.e. at high school and during the first year of university study). According to Wilson-Strydom (2015a), the dimensions of readiness that can stimulate such capabilities are: 1) Decision-making, 2) Knowledge and imagination, 3) Approach to learning, 4) Social relations and social networks, 5) Respect, dignity and recognition, 6) Emotional health, and 7) Language competence and confidence (see fuller descriptions in table below).

Table 5: Wilson-Strydom's capabilities for university readiness

Dimensions of readiness	Description-capabilities for university readiness
Decision-making	Being able to make well-reasoned, informed, critical, independent and reflective choices about post-school study
Knowledge and imagination	Having the academic grounding for chosen university subjects, being able to develop and apply methods of critical thinking and imagination to identify and comprehend multiple perspectives and complex problems.
Approach to learning	Having curiosity and a desire for learning; having the learning skills required for university study; and being an active inquirer (questioning).
Social relations and social	Being able to participate in groups for learning, working

[29] For a discussion on the challenges of school-to-university transitions for engineering students in South Africa, see Case, Marshall, & Grayson (2013).

networks	with diverse others to solve problems or complete tasks. Being able to form networks of friendships for learning support, and for leisure.
Dimensions of readiness	**Descriptions-Capabilities for university readiness**
Respect, dignity and recognition	Having respect for oneself and for others, and receiving respect from others, being treated with dignity. Not being devalued, or devaluing others because of one's gender, social class, religion, or race. Valuing diversity and being able to show empathy (understand and respect others' points of view). Having a voice to participate in learning.
Emotional health	Not being subject to anxiety or fear that diminishes learning. Having confidence in one's ability to learn.
Language competence and confidence	Being able to understand, read, write, and speak confidently in the language of instruction.

Source: Wilson-Strydom (2015a: 131).

4.3 Towards a framework for public-good engineering

The usefulness of the capability approach as a theoretical lens for research in school education and higher education is demonstrated in a number of studies (for example see Boni & Walker, 2013; Hart, 2013; Hart, Biggeri, & Babic, 2014; Vaughan, 2007; Walker, 2003, 2006, 2012; Walker & McLean, 2013, 2013b; Walker, McLean, Dison, & Vaughan, 2010). The subjects explored in such studies range from issues of gendered education (see Unterhalter, 2002; Vaughan, 2007), to engineering education (Boni & Berjano, 2009; Boni et al., 2012; Boni-AristÏzabal & Calabuig-Tormo, 2015; Case & Marshall, 2015).

Broadly speaking, many of these studies are related to student and graduate development, but some explore broader issues such as the role of modern universities (see Boni & Walker, 2013; Walker & McLean, 2013; Wood & Deprez, 2012) or diversifying university access for social justice (Hart, 2013; Walker, 2003; Wilson-Strydom, 2011, 2015a, 2015b). These studies, which examine higher education phenomena through the lens of the capability approach, show its theoretical richness and strength to aid in conceptualizing and providing normative accounts about the changes that need to take place within higher education if it is to contribute to human development and social justice. In this way, my thesis is strategically located between two directions in higher education research. It builds on the work of scholars of engineering education (discussed in chapter 3), and scholars of university education on the nexus of development and sustainability. At the same time, this work takes up theoretical impulses set out by scholars who have applied the capability approach and human development paradigm in higher education and engineering education studies.

Similar to most of the studies mentioned previously, (and as outlined in chapter 1) my interest lies in exploring higher education's contribution to human development. More specifically, I am interested in how engineering education can increase the capabilities and functionings of future engineers, so that they might in turn contribute to expanding valuable capabilities and functionings in society, and by so doing, contribute to sustainable human development. My study is therefore located in higher education research that focuses on rethinking engineering education from a capabilities perspective and builds on work of other researchers (Boni & Berjano, 2009; Boni et al., 2012; Boni-AristÏzabal & Calabuig-Tormo, 2015; Fernández-Baldor, Boni, Lillo, & Hueso, 2014). A good example of a study on engineering education that is inspired by the capability approach is that of Boni et al. (2012) who explore the potential of a curriculum designed to develop cosmopolitanism, drawing on Nussbaum (1997). According to Nussbaum (1997), humanity can be cultivated, and cosmopolitanism can be developed through education that stimulates certain capacities. Namely, capacities for: 1) critical thinking and critical self-examination of one's own culture and traditions; 2) seeing oneself as a human being who is bound to all humans with ties of concern; 3) narrative imagination, which refers to empathizing with others and being able to picture oneself in another person's situation.

In their study, Boni et al. (2012) explore the effectiveness of fostering cosmopolitanism (critical thinking, cosmopolitan ability, and narrative imagination) through subjects offered to engineering students at a Spanish Technical University. In the authors' view, the humanities content in the curriculum followed by future engineers in Spain is threatened as the adaptation process of universities to the requirements of the European Higher Education Area are resulting in a loss of focus on the inclusion of social, ethical, and environmental issues in the engineering curriculum. Subjects included as optional courses in the engineering curriculum at the technical university were ‘Introduction to Development Aid’ and ‘Development Aid Projects’. Boni et al. (2012) argue that through teaching these two subjects, a process of critical reflection was created which ultimately led to the acquisition of an interdependent and global vision of development by students who took the courses, as compared to those who did not. The authors interpret this outcome as indicators of students’ potential to imagine the possibilities of constructing a more just society (Boni et al., 2012).

Similarly, this study seeks to explore ways in which the humanity of future engineers is being cultivated in universities, and to describe what kind of opportunities engineering students have to learn to value human development, sustainability, and social justice as ends of engineering work. That is, the interest lies in exploring the capabilities and functionings enhanced through engineering education in order to theorize how future engineers might consequently do and direct their work, so that it makes contributions that are more effective to sustainable human development. As discussed in chapter 1, Nussbaum (2000) argues that the lack of commitment to specific valued capabilities means limited guidance in thinking about social justice. Thus conceived, it can similarly be argued that a lack of commitment to specific capabilities that are important for public-good engineering means limited guidance in rethinking engineering education outcomes. As the previous section demonstrated, the development of ideal theoretical lists of educational capabilities is very useful for setting the impetus for what it is we believe education should strive for if it is to enhance specific human capabilities.

In summary, this chapter has thus far attempted to show that engineering education can be considered as being in alignment with sustainable human development if it:

1. Enhances students’ valued capabilities,
2. Develops their technical expertise,
3. Provides effective opportunities for students to develop reasons to value social justice,
4. Promotes students’ agency, and inspires them to use engineering knowledge and design for the public-good.

This chapter has also shown that a shift towards viewing sustainable human development as the ends of engineering education requires the identification of appropriate educational capabilities. As Walker (2006) asserts, Robeyns's (2003) criteria for selecting educational capabilities are useful. The process of formulating a provisional list of educational capabilities for public-good engineering entailed the following:

- Considering Robeyns's (2003) criteria as guidelines for sifting through potential capabilities, and distilling the most important ones.
- Drawing from my normative account of engineering education outcomes (refer to chapter 1), the review of literatures on engineering education (chapter 3), and the dimensions of education identified as relevant for public good engineering.
- Analysing how other scholars (i.e. Terzi, 2007; Walker, 2006; Wilson-Strydom, 2015a) have gone about developing ideal-theoretical lists for educational capabilities.

As discussed in chapter 1, the doings and beings that characterise agentic engineers are: the pursuit of goals aligned with principles of social justice (such as poverty reduction); the application of effective power, through individual and collective agency; the pursuit of objectives that are conducive to individual and societal well-being; and, being responsible for engineering outcomes. These characteristics, the corresponding normative account of engineering education, and the dimensions of education relevant for public-good engineering are abstract and theory-laden.

Empirical applications in chapters 6 to 9, elicit the views of practicing engineers, engineering educators and students in order to substantiate these ideas. This is of methodological importance for developing an ideal theoretical list of educational capabilities because it not only reflects adherence to the criterion of 'sensitivity to context', but also allows qualified contributions to my theorizing, which ensures a more comprehensive list of incommensurable capabilities that are actually valued by engineers. The methodological significance of my process of developing an ideal-theoretical list of educational capabilities lies in the fact that I supplement my normative ideas with a combination of German and South African perspectives. The shortcoming of my method is the lack of deep public participation, other than through selected dissemination of the ideas to academic peers (see discussion on public engagement in chapter 10), and participants' voices in the actual research process.

Nevertheless, supplementing the proposed framework (see table 6 below) with empirical data creates a dialogic process in my effort to develop a list, because I allow the participants' perspectives to inform and enrich my conceptualisations. A similar argument is made by Wilson-Strydom (2014) in her development of a capabilities list for equitable transitions to university. She describes a two-step process, which entails the combination of a top-down (theory driven), and bottom-up (empirical) approach to develop her list (Wilson-Strydom, 2014). My proposed framework links the normative objectives of engineering education (discussed in chapter 1) with the four dimensions of education identified as relevant for public-good engineering and it shows the dimensions of learning that can respectively be associated with them

Table 6: Normative framework for public-good engineering education

Normative objectives of engineering education	**Dimensions of education relevant for public-good engineering**	**Dimensions of learning**
Enlarge valued capabilities and functionings of engineering graduates	Education as a capability	Learning to know
Provide opportunities for students to develop, demonstrate and deepen commitment to poverty eradication	Education as a means to social justice	Learning to care
Enhance graduates' ability to acknowledge and exercise their agency	Education as s foundation for agency	Learning to be and learning to do
Promote sustainable human development as a global public-good	Education as sustainable human development	Learning to live together

Source: Authors own

Chapter 5

Methodology

5.1 Introduction

As discussed in chapter 1, the overall aim of this study is to understand the broad range of beings and doings that are enabled by engineering education, as seen from the views of individuals who have studied engineering in Germany or South Africa. A subsequent objective is then to theorise the relationship between these educational capabilities and the potential for professional functioning as agents of sustainable human development. Before discussing the rationale of the research process undergone to address this objective, it is important to restate the aim of the study:

Using the capability approach as a normative framework to define higher education's contribution to human development; this study seeks to explore, describe and combine German and South African perspectives on engineering education in universities and its contribution to sustainable human development.

The research questions that stem from this aim, the literature review, and the theoretical approach are repeated too:

1. How can the capability approach offer a normative critique of engineering education in universities?
2. What capabilities and functionings are enlarged through engineering education? In addition, what implications do they have for pro-poor, public-good engineering?
3. How can engineering education enable graduates, through their work, to function as agents of sustainable human development?
4. How can engineering education also improve graduates' capability for employment?

This chapter explains the processes and procedures undergone in order to develop the most appropriate research design, select suitable data collection methods and methodology required to address the aforementioned research objectives. A discussion of ethical clearance issues is also provided, along with descriptions of how the data was transcribed and analysed.

Towards the end of the chapter, I briefly reflect on my positionality as a non-engineer and non-engineering educator, in my capacity as an engineering education researcher. Thereafter a summative discussion ends the chapter.

5.2 Paradigmatic foundation

Research paradigms are classified in various ways. Some authors suggest four underlying paradigms for research namely: positivism, post-positivism, critical theory and constructivism or interpretivism (Guba & Lincoln, 1994).

Others define paradigms as "basic belief systems based on ontological, epistemological, and methodological assumptions" (Denzin & Lincoln, 1994: 107). Where, according to Denzin & Lincoln (2005):

1. The ontological question is concerned about what form and nature reality takes, and what can therefore be known about it;
2. The epistemological question is concerned about the nature of the relationship between the researcher and what can be known; and,
3. The methodological question is concerned with how the researcher can go about finding out what he/she believes to be known.

According to Maree (2007), in practice, most research paradigms have evolved into hybrid forms that complement each other. For the purposes of this study I take on the same classification as Maree (2007), who looks at interpretivism as the oldest strand in qualitative research from which constructivism emerged (Maree, 2007). Therefore, 'interpretive paradigm' will be used as an overarching concept that covers the assumptions in constructivist theory, which are as follows:

1. The ontological question is answered through concepts such as relativism, where realities are locally and specifically constructed;
2. The epistemological question is transactional/subjectivist and sees findings as being created; and
3. The methodology question is answered through hermeneutical and dialectical methods (Denzin & Lincoln, 1994).

An interpretivist perspective is suited to guide the research design of this study and the data collection process because it is based on the assumptions that:

Human life can only be understood from within. Therefore, the research focus is on peoples' subjective experiences and how they 'construct' the social world by sharing meanings, as well as how they interact with and relate to each other.

Social life is a distinctly human product. This implies that reality is not objectively determined (as it is in positivist thought) but socially constructed; underlined by the assumption that by placing people in their social contexts, there is greater opportunity to understand the perceptions that they have of their own activities.

The human mind is the purposive source of meaning. Therefore, through uncovering how meanings are constructed, we can gain insights into the meanings imparted and thereby improve our comprehension of the whole.

Human behaviour is affected by knowledge of the social world. This means that there are multiple (not single) realities of phenomena, and they can differ at various times and places. As our knowledge and understanding of how the social world is constructed increases, our theoretical and conceptual framework is enriched.

The social world does not exist independently of human knowledge. As such, our knowledge and understanding are always limited to that which we have been exposed, or to our own unique experiences and the meanings we give them. To conceive of the world as external and independent from our own knowledge and understanding is to ignore the subjectivity of our own endeavours (Maree, 2007).

In summary, the ultimate aim of interpretivist research is to offer a perspective of a situation and to analyse the situation under study to provide insight into the way in which a particular group of people make sense of their situation (Maree, 2007). The purpose of the interpretivist perspective is to "advance knowledge by both describing and interpreting the phenomena of the world in attempts to get shared meanings with others" (Bassey, 1999: 44). This interpretation is a search for deep perspectives on particular events and for theoretical insights that may offer possibilities, but no certainties, as to the outcome of future events (Bassey, 1999). An interpretivist paradigm is thus well suited for the purposes of this study, as they require amongst other things, the capturing of qualitative data pertaining to the subjective perceptions of capabilities and functionings enlarged through university learning, based on the views and experiences of engineering graduates, educators, and employers.

5.3 Research approach

Qualitative research is multimethod in focus and involves an interpretive, naturalist approach to its subject matter (Denzin & Lincoln, 1994). More specifically, qualitative research is an inquiry process of understanding, based on distinct methodological traditions of inquiry that explore a social or human problem where the research builds complex, holistic pictures and analyses words as well as reports founded on detailed views of participants (Creswell, 1998). Qualitative inquiry also constitutes asking the types of questions that emphasise 'the why and how' of human interactions and experiences (Agee, 2009), with the goals of understanding the lived experiences of individuals and groups, promoting social change and uncovering subdued knowledge (Hesse-Biber, 2010). The aim and research goals of this thesis can best be explored and described through an approach such as this, which places an emphasis on the qualities of entities, processes and meanings that are not experimentally examined or measured in terms of quantity, amount, frequency or intensity (Denzin & Lincoln, 2005). This means that qualitative research emphasises the value-laden nature of inquiry and looks for answers to questions that underscore how social experience is created and given meaning (Denzin & Lincoln, 2005), in contrast to gathering objective, quantifiable, generalizable data.

Tackling the research questions required gathering rich descriptive data that pertains to individual experiences of engineering education, teaching and learning and engineering practice; therefore a quantitative approach is not suited to achieve this purpose. In contrast to qualitative approaches, quantitative research emphasises the measurement and analysis of causal relationships between variables, and not processes (Denzin & Lincoln, 2005). Experiences of higher education have different influences on people, and human capabilities are perceived subjectively. So, although engineering students might receive similar education in terms of the core curriculum, what they value about it and the professional capabilities and functionings that are enabled by it may manifest in unique ways for each student, especially because of various conversion factors. Of course, there are some assumptions one can make about the value of higher education for graduates (e.g. higher education may be seen as valuable because attaining a university degree enables better chances for employment and a decent income). However, there is a distinctive set of circumstances and motivations for choosing engineering as a preferred means of generating income. Moreover, the professional contexts under which engineers function are different, so a similar set of educational capabilities may not result in the same professional functionings.

For these reasons, a qualitative approach has been selected for the purposes of this study. Also, the qualitative approach taken in this study contributes to the change in focus on quantitative nation-state comparisons which have seemingly led to the dominance of positivistic assumptions, and the prevalence of uncritical international transfer of educational policy and practice, in the international development arena (Crossley & Watson, 2009).

This study therefore employs qualitative research methods to gather thick descriptions, which are not aimed at comparing or generalising findings for the sake of 'borrowing' policy and practice but to help broaden our understanding of what it means to be an engineer in the modern world. Moreover, a capabilities lens on this data widens the range of research questions that can be addressed in engineering education research, thereby creating opportunities to expand current engineering education methodologies (Case & Light, 2011).

5.4 Case selection and participant recruitment

For the purposes of this global South-global North inquiry, one South African and one German higher education institution were selected based on 'best case' criteria. That is, the universities from which students and lecturers were recruited had to have exemplary engineering curricula in terms of addressing sustainable development and/or infusing the humanities in their curricula and pedagogies. Having downloaded recent engineering faculty yearbooks and module catalogues from various universities' websites, I conducted a simple document analysis by searching through them using key words such as 'sustainability' 'sustainable development' 'environment' 'society' and 'communication'. The decision to shortlist universities in this way was fuelled by the idea that it would be more valuable to explore what is already being done in universities to promote sustainable development and to reflect on how this influences attitudes towards, and understandings of, the concept. In South Africa, having considered the University of the Witwatersrand, University of Pretoria, and Stellenbosch University, I chose the University of Cape Town.

In Germany, most engineering programmes are offered by Technical Universities, and I considered the Technische Universität Berlin and Hochschule Bremen, before deciding on Universität Bremen. This decision was also influenced largely by pragmatism, where practical reasons such as close proximity to the area where I was based during my visit to Germany played a role in my decision. In selecting each of the case sites, I considered the reputations of each institutions' engineering departments in relation to their commitment to sustainable development, looked at the course descriptions provided in recent handbooks and yearbooks and conducted a secondary search using broader search phrases like 'environmental impact assessment' or 'lifecycle assessment'. The electronic databases available on university websites therefore made it possible to identify universities' explicit commitments to promoting education for sustainable development within engineering programmes. As such, purposive sampling (Maree, 2007) was used to select the universities.

In comparison to quantitative studies that focus on gathering large, representative samples, qualitative research focuses on smaller groups in order to examine a particular context in detail. The goal is not to provide a broad, generalizable description that is representative of most situations, but instead to describe a particular situation in enough depth that the full meaning of what occurs is made apparent (Borrego, Douglas, & Amelik, 2009). Borrego et al. (2009) provide examples of studies in engineering education literature, discussing a range of sample sizes that can characterise different research projects (see Foor, Walden, & Trytten, 2007; Tonso, 2006; Trevelyan, 2014). The sample sizes and corresponding data collection methods in these examples include, interviewing 55 practicing engineers (see Trevelyan, 2007), observation of 7 student design teams (see Tonso, 2006), and even studying a single individual's case (see Foor et al., 2007).

These studies illustrate how, by reading the rich contextual descriptions afforded by focusing on only a few cases, engineering educators are able to recognize and understand some nuances about the practices that occur within their own schools, which may otherwise have been overlooked when dealing with much larger sample sizes (Borrego et al., 2009). Similarly, I sought to gather thick descriptions based on the views of a select few individuals, whose knowledge, experience and opinions could help answer the research questions.

In order to select appropriate participants for the study, I developed a set of criteria to ensure that I would gather the perspectives of students and lecturers whose experiences with engineering education, and employers whose experiences of engineering practice, were relevant for the objectives of the study. When selecting employers, I sought after professional engineers with extensive work experience in any engineering field, who have worked with or led engineering teams. It was also important to select a diverse group of people in terms of gender, as I was interested in the voices of women (who are underrepresented in the engineering profession). Another selection criteria was employment in companies that explicitly endorse engineering practices that promote energy efficiency, are involved in renewable energies or community development programmes as part of their corporate social responsibility duties, or as reflections of their support of initiatives that are pro-sustainable development. Using existing contacts with a few qualified engineers, I was able to snowball further suggestions for potential interviewees. Ultimately, I was able to recruit 10 employers from across seven medium to large engineering companies that operate in diverse fields in Germany and South Africa (see summary of company profiles in table 7).

With regard to selecting students and lecturers, similar criteria applied to both universities. Students had to be enrolled in a masters degree in an engineering programme that substantially engages with 'sustainable development' in its curriculum. Masters students were targeted instead of undergraduate students because they have more experience that is educational. This means that they are likely to have a wider range of experiences within engineering education from which to draw and formulate their perceptions of how their education has shaped their capabilities and attitudes towards conceptions of development over time.

Table 7: Company profiles

Company	**Main areas of business**
In Germany	
MT Energie	Biogas technology and renewable energies
MT Biomethan	Biogas upgrading technology and natural gas purification
EWE NETZ	Energy, telecommunications and information technology
ProcessQ	Consulting
In South Africa	
Sasol Limited	Energy, chemicals, fuels; coal-to- / gas-to- liquid processing
STEAG Energy	Energy and power plant operations
Group 5 Limited	Construction, manufacturing and infrastructure development

In addition, higher education research that looks at students' perspectives is dominated by undergraduate voices, often at the expense of exploring more mature students' views (which in this case were likely to provide more depth). In order to simplify the recruitment process and help ensure that I selected the most appropriate interviewees, I decided to contact the lecturers first, based on the subjects they taught, their positions within the engineering departments where they worked, and their interest in the research topic. Once I had established contact with the most suitable lecturers and secured appointments with them via email, I then used this contact to create links to students. I asked the lecturers to allow me some time during their lectures to personally speak to students, inform them about my research, and ask for their participation. In some cases, I subsequently requested the lecturers to circulate the information via e-mail and encourage students to take part. Ultimately, in Germany I was able to recruit seven students from Universität Bremen. In South Africa, I recruited 11 students from the University of Cape Town (see summary in table 8).

With regard to the lecturers, 10 were recruited; eight being from the selected case sites (four from the University of Cape Town, four from Universität Bremen) and two from other universities (one from Stellenbosch University, one from the Technical University of Clausthal). I decided to interview these lecturers regardless of this fact and to decide at a later stage if the data could be valuable in addition to that gathered from those individuals who do teach at the selected case sites.

Table 8: Engineering programmes from which students were recruited

Study programme	University	No. of students
Germany		
MSc. Industrial Engineering	Universität Bremen	2
MSc. Production Engineering	Universität Bremen	1
MSc. Process Engineering	Universität Bremen	4
South Africa		
MSc. Chemical Engineering	University of Cape Town	11

It is important to keep in mind that the purpose of this study is not a comparison of views held by specific universities, but rather an attempt to gather perspectives from people whose teaching and learning within engineering has taken place in Germany or South Africa. The selected institutions were chosen because of the probability that they would provide the most appropriate sample of students and lecturers whose views can help answer the research questions, not because views from lecturers who are not employed by the University of Cape Town or Universität Bremen cannot contribute to this end. For these reasons, I decided to keep the two 'outside' lecturers in the sample. In total, I recruited 10 lecturers (five from Germany, five from South Africa) across six engineering faculties (see summary in table 9).

As Florman (1997) attests, we cannot deal effectively with the question of non-technical studies for engineers without considering the views of the students themselves, as well as those of educators and employers of engineers. Moreover, doing so entails reflecting on the role of the engineer in greater society (Florman, 1997). Each group of participants in this study represents different angles from which the field of engineering and its teaching and learning can be viewed. I hoped that employers' views would provide insight into what skills and knowledge matter most for professional functionings, especially with regard to the non-technical beings and doings.

Table 9: Faculties from which lecturers were recruited

Faculty	University	No. of lecturers
Germany		
Applied Mechanics	T. Universität Clausthal	1
Process Engineering	Universität Bremen	2
Physics and Electrical Engineering	Universität Bremen	1
Production Engineering	Universität Bremen	1
South Africa		
Chemistry and Polymer Science	Stellenbosch University	1
Engineering and the Built Environment	University of Cape Town	4

The views from lecturers were sought to provide insight into what it means to 'teach' engineering for this purpose, and the challenges and opportunities that exist within universities to achieve this. Finally, looking at engineering education from the perspectives of students was done with the intention to shed light on ways in which their educational capabilities and functionings were shaped by university learning, and to understand what they value about it beyond skills for employment. Ultimately, the participants were selected in the hope that their respective perspectives could provide data that could be used to fulfil the aim of the study.

Before discussing the specific methods used to collect data or describing the data collection process, it is important to discuss issues of ethics in research, ethical clearance procedures, and their influence on access to research participants. These are aspects which had to be considered and dealt with after the research participants had been shortlisted, and before data collection could begin. In the following section, the procedures followed to contact the selected individuals and seek their agreement to participate in the study are discussed in further detail.

5.5 Principles for ethical research

Ethics in research is a situated practice that involves the balancing of ethical principles that are often abstract and not obvious in their application (Denzin & Lincoln, 1994). The ethical principles which guided the research procedures for this study include concerns for the protection of research participants' identities, respecting their rights to privacy and confidentiality and ensuring informed consent and rights to voluntary participation (Denzin & Lincoln, 2005; Maree, 2007; Piper & Simons, 2005). These principles informed the drafting of both the information letter and informed consent form, which were sent to the participants prior to meeting them for the interviews or focus group discussions. Informed consent means that those participating in the study (in this case the engineering employers, lecturers and students) should have full knowledge of the research and the consequences of their participation ahead of agreeing to participate (Piper & Simons, 2005). As Piper and Simons (2005) point out, achieving informed consent is not always a straightforward task as there can be tension between fully informing and gaining access, and it may not always be possible to foresee all consequences in advance. Piper and Simons (2005) suggest 'rolling informed consent' as a more appropriate strategy, where renegotiation of informed consent can take place once the research is under way.

To ensure informed consent for the participants of this study, all interviewees were informed in advance in writing, via e-mail, about the research project, its purposes, and the nature and purposes of the respective interviews and focus group discussions. An 'information page for research participants (see appendix A) was sent to all of the recruited individuals, whose e-mail addresses I had accessed from the company or university web pages. In the case of the students, I requested the lecturers to forward the email on my behalf, once I had met them in person, as lecturers are not allowed to share students e-mail addresses. Because my contact information was included in the information page, interested students were able to contact me directly. All participants who were informed about the research in this way and agreed to participate in the study, also agreed to the conditions stipulated in the 'informed consent form' (see appendix B). Therefore, there was no 'rolling informed consent' because there were no amendments that had to be made to the initial terms and conditions. These terms and conditions included that participants were willingly involved in the research and that they had been informed about its purposes and research methods to be used. Additionally, the consent form informed the participants that the interviews or focus group discussions would be recorded and that excerpts of the transcripts would be quoted in this thesis.

Confidentiality is a principle that allows people not only to talk in confidence, but also to refuse to allow publication of any material they think could harm them in any way, while anonymization is a procedure to offer some protection of privacy and confidentiality (Piper & Simons, 2005). However, the context often reveals clues to identity even when names, places, and institutions have been given pseudonyms; also, not all people in a research study can necessarily be anonymised. As a result, the names of the companies and universities referred to in this study are real names. However, in order to protect the identities of the participants, all the names of the students, lecturers and employers quoted in this thesis are pseudonyms. Although there were participants who had no objections to using their real names, for uniformity purposes pseudonyms are used for all participants.

In addition to adherence to research principles such as privacy, confidentiality and informed consent, there are some procedures that had to be followed in order to gain institutional permission to access students and lecturers at the University of Cape Town. Getting this permission required applying for ethical clearance before recruiting participants at the institution. In the next section, I reflect on this process and discuss some interesting issues in relation to accessing universities for the purpose of research.

5.6 Access and ethical clearance procedures

Gaining access to research participants was straightforward with engineering employers as well as students and lecturers at Universität Bremen. In the case of the employers, there were no specific company rules about permission to approach individuals for participation in research projects. Similarly, Universität Bremen does not have standardised ethical clearance procedures or rules that govern how one should go about approaching university students, lecturers, or staff members when seeking participants for a research project.

According to Oellers and Wegner (2009), this can be attributed to the fact that in Germany, ethical requirements for research vary strongly across research fields where requirements are high and legally binding in medical/biomedical research but low in the social sciences. In social sciences research, there is no legal regulation for approval of research through a research ethics committee and the only legal requirement to take into account is federal data protection (Oellers & Wagner, 2009). The federal data protection law addresses issues of consent, data gathering, storage, and processing for all kinds of research and it elaborates some general standards for data related issues in scientific research, such as the duty to anonymize information (Oellers & Wagner, 2009).

While there are usually no research committees in universities that are mandated to approve research projects from an ethical point of view, there are general standard guidelines about good scientific practice, established by the German Research Association, known in Germany as the *Deutsche Forschungsgemeinschaft* (DFG). These guidelines encompass all fields of scientific research and focus strongly on questions of ethical behaviour among researchers. The DFG recommends that universities establish their own guidelines based on those provided by the DFG. Although German universities continue to adopt either the DFG's rules or elaborate their own, by and large, universities do not enforce ethical clearance procedures (Oellers & Wegner, 2009).

In South Africa on the other hand, ethical clearance procedures are widely enforced by higher education institutions and there are stricter rules that govern access to research participants who work or study at a given institution. For example, in order to gain access to students and staff at the University of Cape Town, it was mandatory to go through several processes for ethical clearance. Ultimately, I submitted applications to obtain ethics approval and clearance (see appendix C) from the ethics committee for the Centre for Higher Education Development. I then applied for ethical clearance from the Faculty of Engineering and the Built Environment and once this had been cleared, I was able to approach the Department of Student Affairs (for permission to recruit students) and the Department of Human Resources (for permission to recruit lecturers). This was necessary because the University of Cape Town has several ethics committees, with one for each of its seven faculties, and some of these provide oversight for committees that function in particular departments and institutes.

In agreement with Oellers and Wegner (2009), I regard research ethics as being about social responsibility and going beyond legal regulations. Therefore, ethics frameworks should give priority to raising awareness of ethical principles in research; principles like the protection of research participants' rights to privacy, confidentiality and voluntary participation. Such principles should encourage researchers to consider the ethical dimension of their work, and the responsibility of research ethics committees is to help ensure that this happens. While it appears that German universities might benefit from more rigorous research ethics monitoring for the social sciences, it is also important to guard against ethical clearance requirements that create too many bureaucratic hurdles for researchers, which can be the case in South African universities. The rules and regulations of ethical clearance procedures required by universities ought to protect the rights of the research participants and ensure appropriate conduct for data access, gathering, processing, and dissemination without being unnecessarily dogmatic. That is, the rules that govern ethics clearance procedures should themselves be periodically critically reviewed for relevance and obstruction to advancing academic research.

Having discussed how I went about establishing contact with the research participants, my discussion turns to how I collected the data, which is the empirical foundation of my study.

5.7 Collecting the data

5.7.1 Semi-structured interviewing

According to Maree (2007), semi-structured interviews allow the researcher to best define the line of inquiry, but at the same time provide room to identify emerging lines of inquiry that are directly related to the study objectives, which can further be explored and probed. Two different interview guides with a unique set of predetermined questions were developed for gathering data from employers and lecturers (see appendices D and E) through semi-structured interviewing. In these interview guides, open questions (e.g. What are the purposes of engineering education?) were paired with theory-driven questions (e.g. How important are soft skills and transversal skills in engineering practice?). As Flick (2009) asserts, doing so allows the researcher to gather interviewees' responses based on the general knowledge they have on hand, while allowing their implicit knowledge to be made more explicit. Through this type of questioning, I sought to extract the interviewees' general opinions on some aspects, but also allow space for them to share deeper, more thoughtful subjective reflections on other aspects. This kind of interviewing was also selected due to the nature of the topic (perspectives on engineering education) which necessitates gathering data that explicitly targets how the selected participants see and/or think about universities, teaching and learning, engineering education, engineering, development, sustainability etc. Semi-structured interviews with well-formulated guiding questions are well suited to capture these intersubjective views. The richness of the data that can be captured in such interviews lies in how the participants articulate their perspectives based on their knowledge, subjective experiences, reflections, and observations. As such, the interview guides were designed to stimulate the interviewees' critical reflection and at the same time lead a conversation that would allow their voice to take centre stage, without deviating too far from the purposes of the study, as dictated by the research questions.

As discussed in the review of literatures (chapter 3) desirable engineering graduate attributes range from technical, to soft and transversal skills. In general, there appear to be no significant debates about the fundamental importance of technical skills for the engineering profession. That is, there is a broad consensus in literature that technical skills are the cornerstone of engineering tasks. On the other hand, there appears to be some contestation about soft-skills, in terms of the weight they should carry on the list of graduate attributes, or the overall skill set of the professional engineer. Therefore, for the employer group, the purpose of the interviews was to interrogate the importance and relevance of 'soft' and transversal skills in engineering practice. In particular, the intention was to gather opinions on a range of issues related to non-technical knowledge and skills, as a means of verifying some common findings in literature about engineers' lack of 'soft skills' like communicating effectively and team work. I also wanted to explore the employers' understanding and appreciation of transversal skills like ethical learning and cosmopolitan abilities, which are extrapolated from engineering education literature. Also, while there are many studies that involve engineering employers' perspectives as their main source of data, the focus is often on graduate employability (for example see Griesel & Parker, 2009) and seldom on how engineering employers think about the significance of engineering work in relation to broader social issues related to sustainable development. I wanted my interviews to capture a broad spectrum of topics that include, but are not limited to 'skills and employability' in engineering.

In order to ensure that the interviews dealt with this variety of matters, I divided it into three sections. The first section of the interview contained questions asking the employers to tell me what they look for in an engineering graduate in terms of both technical and non-technical skills. The second section focused on the employers' thoughts on soft-skills and transversals and asked them to talk about engineering and societal development, as well as reflections on engineers' roles in promoting sustainable development. The final section of the interview asked questions about the education of engineers, and was geared towards understanding what the employers thought universities should do to develop the ideal engineer. This section of the interview also asked employers to share their thoughts on the role of the humanities in engineering education.

The employer interviews were carried out between July and December 2013, ahead of collecting data with lecturers and students. This was done intentionally, with the view that some of the findings from employers' perspectives could help inform questions in the interview guides for lecturers and students.

For the lecturer group, the purpose of the interviews was to gather perspectives on engineering education from individuals who have extensive experience in its teaching. Unlike the employer interview guide which was divided into three sections, the guiding questions for lecturers were in a continuous form, uninterrupted by section headings (topics) and slightly more philosophical in nature. Nevertheless, there were also questions that were directed at the lecturers' personal teaching styles, assessment of learning outcomes and thoughts on ways of teaching soft-skills and sustainable development through engineering curricula and pedagogies.

The first few questions were similar to those that were asked in the employer interviews and were related to the importance of soft and transversal skills, but the focus was more on how the lecturers understood the purposes of engineering education and its outcomes. Thereafter, I asked the lecturers to talk about their own pedagogical approaches, especially in relation to enhancing students' critical thinking abilities and for them to discuss some courses they taught or knew off, which they felt encouraged the development of soft skills. The attention of the interview then turned to discussions on the concept of 'development' and technological innovations geared towards it. We also discussed challenges posed by climate change, and considered how they are related to engineering education. The last few questions of the interview focused on teaching 'sustainable development' and how the lecturers saw links between universities, engineering and sustainable development.

Semi-structured interviewing allowed me to ask pre-determined questions (which were informed by literature, my conceptual framework, and most importantly the research questions) while allowing room to ask probing questions that were born out of some curiosities triggered during the conversations. It is interesting to note that while the employer interviews consisted of 15 questions, and the lecturer interviews 10, the duration of the employer interviews averaged 35 minutes, while the lecturers averaged an hour. The difference in duration may be a result of the nature of the questions i.e. more philosophical questions in lecturer interviews that may have demanded more time to answer.

5.7.2 Focus group discussions

A focus group is a qualitative data collection method that entails an informal discussion about a specific topic, among a small group of selected individuals (Denzin & Lincoln, 2005; Maree, 2007). The participants of a focus group are usually selected on the basis of the similarity of their social and cultural backgrounds or experiences and concerns (Wilkinson, 1998). As discussed in section 3.4, the students were selected based on their enrolment in a masters degree in engineering at one of the selected universities. Therefore, what the students have in common across both universities is a similar educational background. Within each of the universities, the students also have in common, the institution in which their educational experiences have taken place as well as their cultural backgrounds (not so much in the case of South Africa).

What takes place during a focus group is a discussion of a specific issue/s with the help of a moderator, whose role it is to stimulate and guide the conversation, which should take place in a setting where participants feel comfortable enough to engage in a dynamic discussion for one or two hours (Liamputtong, 2011). In this study, I took on the roles of moderator and researcher, having done the groundwork of recruiting and selecting the participants, setting the research agenda and collecting the data myself. In order to ensure that the selected participants would feel comfortable to engage in the discussions, I suggested meeting at venues on the university campus such as a tearoom, or empty office spaces designated for interviews. One focus group discussion ultimately took place outside, in a park at the Bremen University campus, as the students insisted all the indoor meeting options were too hot and stuffy, and that they would feel more comfortable sitting on the grass, outside any of the university buildings. Other efforts to create a comfortable setting, included providing refreshments (mineral water, mints) and for the German students, encouraging them to speak German throughout the discussions if they preferred. I also allowed the students to suggest meeting times that were most suitable for them.

According to Hennink (2007), focus groups do not aim to reach consensus on the discussed issues; rather, they "encourage a range of responses which provide a greater understanding of the attitudes, behaviour, opinions or perceptions of participants on the research issues" (Hennink, 2007: 6). A successful focus group discussion relies heavily on "the development of a permissive, non-threatening environment within the group" (Hennink, 2007: 6), where the participants can feel comfortable to discuss their opinions and experiences without fear that they will be judged, ridiculed or made fun of by others in the group. As Morgan (1988) asserts, focus groups are useful for exploring and examining what people think, how they think, and why they think the way they do about issues that matter to them, without pressuring them into making decisions or reaching an agreement (Morgan, 1988). The method is especially valuable for permitting the participants to develop their own questions in their own words and on their own terms, which creates a space for the researcher to gain insight into the similarities and differences of understandings held by people (Liamputtong, 2011). If carried out appropriately, the method enables researchers to examine how such understandings differ by social groups, such as social class, age, gender, ethnicity, profession etc. (Conradson, 2005).

Focus groups are particularly suitable for exploring issues where complex patterns of behaviour and motivation are evident or where participants hold diverse views (Conradson, 2005). In a focus group setting, where the interactions occur between the participants themselves rather than with the researcher, the participants are likely to talk more openly. Also, the researcher is also provided with opportunities to follow up on comments made during the discussion and to cross-check with the participants in a more interactive manner than a questionnaire or individual interview can offer (Conradson, 2005). For people who find one-on-one and face-to-face interaction intimidating or 'scary', the group interview may offer 'a safe environment where they can share ideas, beliefs, and attitudes in the company of people with whom they share similarities (Madriz 2003). However, this does not guarantee that each participant will speak or actively take part in the discussion.

There are some challenges posed by focus group discussions as a method of collecting data that are important to note. Like any other research methods, focus groups do not suit all research aims and there have been times when they were found to be inappropriate or problematic, especially when the topics under discussion are of a very personal matter (Liamputtong, 2011). Focus groups may also not be sufficiently in depth to allow the researcher to gain a good understanding of the participants' experiences, especially because there are multiple lines of communication during the discussion (which can also cause challenges for transcribing). In some focus groups, certain personalities of the participants (such as dominant or aggressive personalities) may strongly influence the direction of the discussion or dominate it (Krueger & Casey, 2000, 2009). While in others, due to the presence of some group members, the participants may feel too intimidated to speak. In other situations, participants may simply conform to the dominant ideas present in the group (Krueger & Casey, 2009). As such, the quality of the data generated is affected by the characteristics and context of the focus groups.

Keeping these challenges in mind, I set about compiling the focus group discussion guides. Unlike the semi-structured interviews with employers and lecturers, the interview guides for the focus group discussions were more structured but the questions more open and less theory driven. The interview guide (see appendix F) comprised of 10 questions, which fell into four subsections. The purpose of the focus group discussions with students was to understand how they view the purposes of their studies, why they wanted to become engineers, how they identify with the profession and how they see the role of engineers in society. Therefore, the first section of discussion focused on talking about the students' intrinsic motivation to study engineering. Thereafter the discussion turned to the students' perceptions of learning soft skills, before moving on to questions surrounding their thoughts on the meaning of sustainable development. The discussion was concluded by students' outlooks for their futures.

Ideally, I hoped that each focus group would comprise of four students, as I wanted to keep the groups small and therefore more manageable in terms of moderating the discussion and having a good overview of the group dynamic. Ultimately, the perspectives from 18 students were gathered in four focus group discussions. One student from the University of Cape Town was unable to join the discussions on the dates that meetings had been scheduled, but agreed to have an individual interview on a separate day. I used the same discussion guide for his interview. In comparison to the focus groups, this interview was longer, and I anticipate that the students in the focus group discussions may have sometimes kept their input short, out of politeness to let other students speak. In contrast, the responses provided by this student were more of the 'story telling' kind. As a procedure for member checking, before moving on to a new different section of the interview, I often asked participants if I had understood their sentiments well by paraphrasing their responses and asking them to comment on my understanding.

To summarise, data was collected using semi-structured interviewing with engineering employers and lecturers, and focus group discussions were used to capture the views of students (see summary below).

Table 10: Summary of data collection methods

Research participants	Data collection methods
Employers (N=10)	10 Semi-structured interviews
Lecturers (N=10)	10 Semi-structured interviews
Students (N=18)	4 Focus group discussions

5.8 Transcribing the data

All interviews and focus group discussions were audio recorded and transcribed verbatim (see example of transcript, appendix G). Ultimately, one focus group discussion, three employer interviews and two lecturer interviews were conducted in German i.e. 8 German participants preferred speaking German, and nine preferred speaking English. I directly translated all the German responses myself as I am fluent in German and hold a level B2 German language certificate. My translations were crosschecked by a German native speaker for inaccuracies.

In all transcripts, behavioural aspects of the conversation were not mentioned in the analysis and interpretation of text. The transcripts were written according to standard norms of written language and deviations of the spoken language, such as the omission of sounds or the blending of sounds, were mostly ignored. The transcription procedure was mainly aimed at the verbal aspects of communication, in the interest of an analysis and interpretation procedure that would be based on the words spoken and the interview content. However, as Kitzinger (1994) argues, in coding the transcript of a group discussion, it is worth using special categories for certain types of narrative, such as jokes and anecdotes, and types of interaction, such as ‘questions’ ‘deferring to the opinion of others’ ‘censorship’ or ‘changes of mind’. According to Kitzinger (1994), such annotations in the transcript help ensure the descriptive integrity of a focus group research report. That is, a descriptive report that is true to its data should also usually include at least some illustrations of the talk between participants, rather than simply presenting isolated quotations taken out of context (Kitzinger, 1994). Although these annotations are closely related to the coding process, they are not examples of coding per se, as they are more for capturing the dynamic of the focus group, as opposed to being a means to identify themes. The coding and analysis procedure applied to all transcripts is described next.

5.9 Analysing the data

There are various ways of analysing qualitative data, with each method offering the possibility of different insights. For example, content analysis can be used to identify patterns of speech that are indicative of particular attitudes or to create aggregate accounts of inferences from data (Krippendorff, 1989). Hermeneutics can be used when the intention is to decipher or peel back layers of hidden meanings in the apparent significance of textual data (Ricoeur, 1976). When the research seeks to understand how meanings are shaped in the context of exchange, conversation analysis can be used as it focuses on the orderliness, structure and sequential patterns of interaction (Maree, 2007).

On the other hand, discursive analysis can be applied when one seeks to reveal sources of power, dominance and inequality and how these sources are established, maintained or transformed in specific contexts (Maree, 2007). When seeking to identify narrative threads and temporal or spatial themes from people's 'stories', narrative analysis would be an appropriate method (Guba & Lincoln, 1994; Maree, 2007). The commonality these methods (and other qualitative data analysis methods) share is an iterative approach which is aimed at understanding how participants make sense of the phenomenon under study (Bryman & Burgess, 2002; Flick, 2009; Hesse-Biber, 2010). The process of data analysis in qualitative research involves working with, and searching for patterns in the raw data in order to break it down, discover what is important and what is to be learned before synthesising the data and deciding what should be shared (Bogdan & Biklen, 1982). In this study, the data consisted of interview and focus group transcripts, and the purpose of the analysis process was to identify themes that are important to the research questions. Thematic analysis was therefore applied in a 'line-by-line' coding manner which draws heavily from grounded theory (Glaser & Strauss, 1967) analysis techniques.

Although essentially suited for studies in which the generation and development of theory is the primary concern, I decided to apply analysis techniques which were developed for grounded theory research (Corbin & Strauss, 1990, 2014; Corbin & Strauss, 2008; Glaser & Strauss, 1967), because it facilitates unrestrained emergence of themes, hence lending itself well to the exploratory-descriptive dimension of my research. Grounded theory was developed by Barney Glaser and Anselm Strauss, and it is a research methodology in the social sciences emphasizing the systematic generation of theory from data (qualitative data in most cases) in the process of conducting research. Unlike traditional logico-deductive theorizing methods that require a priori assumptions up front that later have to be verified, in grounded theory, the formulation of a hypothesis before collecting data is not done. This study is intended to aid the exploration and description of capabilities broadened by university learning, based on subjective perceptions. Such data is best analysed not measured against predetermined assumptions, but rather through a coding and conceptualization process which allows unconstrained emergence of themes (Corbin & Strauss, 2008).

Therefore, although the interview guides were arranged thematically, I wanted to apply an analysis technique that opens up possibilities to discover new sets of themes. As such, rather than seeking to offer static descriptions of the data which are expressed strictly in terms of causality (Lawrence & Tar, 2013), the intention was to develop context-based descriptions of multiple views concerning the contribution engineering education in universities makes to sustainable human development.

The four stages in the cycle of analysis consistent with grounded theory that were applied to the transcripts are coding, conceptualizing, categorizing, and theorizing (Glaser & Strauss, 1967). The step-by-step procedure I therefore followed in analysing the interviews and focus group discussion was as follows:

1. Coding, which entails reviewing the transcripts sentence by sentence to identify anchors (words or phrases) that allow the key points of the data to come forward;
2. Conceptualizing, which means grouping codes with similar content (where new concepts are core parameters of the data and codes can be seen as dimensions of these concepts);
3. Categorizing, which is about developing categories that broadly group the concepts and constitute the basic elements to be generated into a hypothesis or a theory; and
4. Theorizing, which is the process of constructing a system of explanations for the main concerns of the subject of the research.

As opposed to constructing a system of explanations for the perceptions held by the participants, my aim was to propose a framework of engineering education for sustainable human development. It is also important to note that the intention was not to carry out a grounded theory study. Rather I sought to make use of the procedure outlined in grounded theory as a means to guide the analysis of the qualitative data gathered in this study. That is, I did not employ grounded theory as a methodology, but applied some techniques consistent with grounded theory as an aid to the analysis process.

Interpretive rigor requires the researcher to demonstrate clearly how interpretations of the data have been achieved and to illustrate findings with quotations from, or access to, the raw data (Rice & Ezzy, 1999). The participants' reflections, conveyed in their own words, strengthen the face validity and credibility of the research (Patton, 2002). For these reasons, excerpts from the raw data are provided in my discussion of the findings in order to demonstrate that my interpretation remains directly linked to the words of the participants (Fereday & Muir-Cochrane, 2006).

5.10 Researcher positionality

It must be mentioned that I am neither a qualified engineer, nor an engineering educator. This means that my knowledge and understanding of the engineering profession and engineering education is theoretical, not practical. My decision to focus on the education of engineers therefore does not stem from any sort of affiliation with engineering, but rather it was based on the belief that the work engineers do is more intertwined with 'development' than any other profession.

As discussed in chapter 10, my positionality as a non-engineer was advantages for bringing attention to aspects of engineering work that engineers themselves sometimes take for granted. Therefore, although I do not bring expert engineering knowledge to this project, my interaction and discussions with people who do function as students, teachers and practitioners of engineering enrich my understanding and perspective of what it means to 'do' engineering, or be an engineer. In the process of carrying out this study, I therefore came to realise that interdisciplinary scholarship can have synergetic outcomes. While I was able to gain insight and broaden my perceptions about teaching, learning and the values associated with engineering education, the research participants had the opportunity to reflect on the greater significance of their day-to-day functionings, and the depth of the data gathered for this study was enhanced by our diverse and multiple perspectives.

5.11 Summative discussion

This chapter covered all issues related to the methods and methodological approach used to gather the empirical data of this study. Having introduced the paradigmatic basis of the study, the chapter described the design of the study and highlighted its merits and drawbacks. In doing so, the chapter defended the appropriateness of the exploratory-descriptive, qualitative, research design and provided reasons why alternative (quantitative) research approaches were not used. The data collection methods (semi-structured interviews and focus group discussions) were also discussed. It is important to highlight that although designed with different objectives, in all interviews and focus group schedules, special attention was permitted to issues surrounding sustainable development. Therefore, questions asked across all groups included those related to: what sustainable development means, why it is relevant in engineering education, how it is taught, how and what students learn from it and how engineers exercise their agency to contribute towards it in practice.

Issues of access to research participants, ethical clearance procedures and the importance of ethical principles in research were also discussed before explaining how the interview and focus group recordings were transcribed in preparation for the analysis process. The data analysis procedure was described, paying attention to how the interview transcripts would be coded, what the intention of the analysis was, and how I hoped to synthesize the findings. These findings are discussed from chapter 4 through to chapter 7 and conclusions are drawn in chapter 8. As such, this concludes the first part of the thesis, which has dealt with the contextual, theoretical, conceptual, and methodological aspects of the study. The remaining chapters reveal the findings and results of the study, address its research questions, and draw conclusions.

Part II

Results of the study

Chapter 6

Employers' views on education for public-good engineering

6.1 Introduction

This chapter attends to perspectives from industry and draws from the qualitative responses of a sample (N=10) of international engineering employers located in Germany and South Africa. Data was collected between July 2013 and January 2014, ahead of gathering data with students and lecturers at the selected universities. Because engineering students are educated for assuming various roles and functions in industry, interviews were conducted with engineering employers first to explore what technical skills and so-called soft skills are most wanted and valued by individuals who represent industry. The interviews also aimed to challenge some assumptions about skills and competences generally regarded as crucial for the engineering profession, with the intent to depict varying views concerning what matters most with regard to what engineers can do and be to enhance human well-being. Also discussed in this chapter is how the selected employers perceive the role of engineers in advancing sustainable development through their work, how they view the shortcomings and strengths of universities with regard to engineering education, and what type of education might then be required in the future.

Questions addressed in this chapter include the following: What does industry require of engineers today? What attributes are engineering graduates bringing into the workplace? To what extent do these attributes satisfy industry demands? Moreover, do such attributes enable graduates to practice public-good engineering? In order to present answers to these questions in a manner that represents the views of the interviewees, the chapter draws substantially on the voices of the employers. That is, summaries of my interpretation of their answers are interjected with interview excerpts. This deliberately focuses the attention of the chapter on the employers' responses allowing these to stand out and dominate the text, while allowing some transparency of the data analysis process. The results are discussed thematically, in accordance with the categories that resulted from the data analysis. This means that the headings represent the categories (step 3 of analysis procedure) which emerged from the data.

The chapter begins with a discussion on the makings of the ideal engineer, followed by a discussion on valuable transversal skills, then public-good engineering. This is followed by discussing what universities can do to provide engineering graduates with the capacities to practise this type of engineering. Special attention is permitted to the views of the two women in this group of employers, without imposing gender specific generalisations of their responses in the rest of the discussion. Instead, their unique perspectives are highlighted and considered for their relevance in defining public-good engineering. The summative discussion at the end of the chapter looks at the implications of understanding these findings through the lens of the capability approach. For background and orientation purposes, some information is provided about the selected employers before moving on to presenting the interview findings. Also for orientation purposes, the responses of the participants are marked 'GER' for Germany and 'SA' for South Africa.

6.2 Introducing the employers

All but two of the interviewees were male, between the ages of 40 and 60, had engineering qualifications or natural sciences educational backgrounds, with considerable experience (on average 18 years) working in engineering firms or with engineers and engineering teams. Both female interviewees are from the South African sample of employers, with one holding a social sciences qualification (see summary of profiles in Table 7). Their individual profiles are as follows:

6.2.1 German employers

1. *Matthias Klemp* holds a masters degree in physics and is a technical director at MT Energie, a private company that focuses on the production of electricity from renewable sources.

2. *Sebastian Braun* has a background in mechanical engineering, economics, and mass production. He currently works as a project manager in industrial projects related to process technologies for MT Energie. In 1997, he founded an engineering firm in Graz (his home town) which deals particularly with mechanical engineering project management, offering site supervision and consulting services.

3. *Thore Lehman* is a qualified process engineer. He works as a technical director at MT Biomethan (a subsidiary of MT Energie) with engineering teams involved in the construction of biogas power plants and is in charge of the technology, production, and quality management divisions.

4. *Theodor Klein* has a background in mechanical and production engineering with a specialisation in process engineering. He also holds a Ph.D. in process engineering and currently works as a project manager for EWE Netz.

5. *Rolf Weiss* is qualified in the field of energy and process engineering. He holds a Ph.D. in process engineering, and he has been employed as a quality, operations, and logistics manager. In 2008, he founded his own company, ProcessQ, which offers consultation services to small and medium sized companies focusing on organisational development and quality management.

6.2.2 South African employers

1. *Claire White* is a chemical engineer by training who spent her early career years working in engineering production, and moved into control engineering before getting involved with the recruitment and, training and development of young graduate engineers at Sasol.

2. *Pravesh Kumar* is a senior project engineer at Sasol Technology, with an electrical engineering background. He has been involved in plant maintenance and leading projects at power stations at Sasol Oil and Sasol Technology for over twenty years.

3. *David Schrader* is a managing director of STEAG Energy Services South Africa, with a background in process engineering. Of German descent, he earned his qualification through a combination of vocational training and engineering studies at a technical university in Germany. He has twenty years work experience (mostly in South Africa).

4. *Paul Chambers*, who holds a BSc in civil engineering and a Master of Business Leadership (MBL), is an engineering director within the engineering and construction cluster of Group 5, one of the largest construction companies in South Africa. The sectors in which the company operates include road, power, oil and gas as well as housing and transportation.

5. *Cindy Shaw* (the only non-engineer amongst the interviewees) holds an MBA in organisational learning and a doctorate in organisational behaviour. She is mostly involved with management and leadership development and heads the graduate recruitment, selection and development unit of Group Five’s engineering bursary division.

Table 11: Employer profiles

Interviewee	Company	Qualification/background
From Germany		
Matthias Klemp	MT Energie	MSc. Physics
Sebastian Braun	MT Energie	Mechanical Engineer
Thore Lehman	MT Biomethan	Process and Industrial Engineering
Theodor Klein	EWE NETZ	PhD. Process engineering
Rolf Weiss	ProcessQ	PhD. Process Engineering
From South Africa		
Claire White	Sasol	Chemical Engineer
Pravesh Kumar	Sasol	Electrical engineer
David Schrader	STEAG Energy	Process engineer
Paul Chambers	Group Five	Civil engineer
Cindy Shaw	Group Five	PhD Organisational Behaviour
Total: 10 (Note: 8 male, 2 female).		

6.3 The qualities of an ideal engineer

As discussed in the previous chapter, the employers were asked a series of questions across three broad categories: views on engineering graduate attributes, perceptions of 'soft' or transversal skills, and comments on engineering education in universities.

In describing the ideal engineer, beyond naming task specific technical skills, the employers spoke of personality characteristics, attitudes, values, and attributes that they found desirable for the professional engineer to possess. It is notable that among all employers interviewed 'the engineer' is usually referred to as male, describing the engineer as 'he'. Although gender-neutral pronouns are often used for example "the ideal engineer is 'someone' who…" the employers never refer to the engineer as 'she'. Although this may be coincidental, it is also possible that these responses signal the awareness and acknowledgement of ongoing male dominance in engineering; Paul Chambers (SA) even refers to the industry as the 'engineering fraternity' in one of his responses. In the passages that follow, I underline words such as 'he' and 'his' (just in section 6.3) to highlight the frequency of referring to engineers as male. This indicates that the male engineer is still seen as the norm, and it suggests that being a woman engineer marks one out as unusual (Faulkner, 2010).

Thore Lehman (GER) describes an ideal engineer, emphasising the necessary foundation of a comprehensive education upon which accurate decisions can be based and assessed:

> *I believe the perfect engineer should first of all, have a very good education because the job consists of highly specialised tasks. And so, regardless of what one does, they should have the capacity to- based on a sound education- he should be able to evaluate the precision of his actions in terms of how close or far one gets to the desired outcome. And I think a good educational foundation sets the premise for an individual's ability to develop a sense of Ordnung*[30]*. And I think this is very important, in order to avoid very bad results*.

Theodor Klein (GER) talks about the importance of the ability to apply theoretical, analytical, and technical knowledge in practice, stating that this is however a basic expectation, pointing out that this alone cannot characterise the ideal engineer:

> *The ideal engineer is an engineer who can marry praxis with technique. An engineer who is a technical expert, that's great, obviously, but an engineer who knows how to apply theory to praxis…and then not just the hard skills- that means how should he carry himself in certain projects? How should he carry himself amongst different stakeholders in the project? I believe that those are the soft skills that are very important, not just that what he is capable of, technically, but how he can communicate that.*

Reference to the importance of effective communication occurs frequently in the interviewees' responses, often brought up during the interviews outside the context of questions related to communication specifically, as is the case above. Rolf Weiss (GER) is the only interviewee to bring up intrinsic motivation to pursue the engineering profession as a distinguishing factor of a prime engineer, referring to passion and interest in technical subject matter as 'stand out' traits. He also talks about the difficulty of describing the ideal engineer because of the complexity and diversity of the disciplines and areas of application there are in the profession:

> *I think that's impossible [to describe the perfect engineer], because there isn't an ideal person (…) and I think the tasks that engineers have to do are as multifaceted as*

[30] *Ordnung* is a German word which usually refers to order or orderliness as well as arrangement, discipline or system. It is also commonly used to describe stereotypical notions of German culture or life in Germany.

people are. So what distinguishes an engineer is, definitely fun with technology, so simply having fun with the material, the sense behind that, and the ideal engineer just like the ideal person is someone who is opportunity oriented, right? [And] not too blinded by technique and easily lost in the details.

Mr Weiss (GER) warns not to get 'blinded by technique' and 'lost in the details'- accentuating the notion that there is a certain point at which technical expertise alone has little or no added value to engineering practice if not accompanied by broader skills and knowledge. Another desirable attribute described by Matthias Klemp (GER) is persistent willingness to learn. He talks about one's learning time at the university ending, and the role industry takes over in developing the graduates:

Besides that, it's quite important that people have the ability to show the ability to learn and show the ability that they want to learn. Because being educated is just one thing and finally during the professional lifetime there is a process going on making the engineers more valuable because they learn along their working lifetime.

Mr Klemp's (GER) words allude to life-long learning as a desirable ability for engineers and as an important outcome of university learning. The above excerpt also suggests that teaching and learning is the responsibility of the university (engineering education), the individual (engineering students), and industry (engineering employers). This reminds us of the important role industry plays in continuing engineers' education through on the job training. The importance of learning which takes place once an engineering graduate enters the job market is also evident in the fact that practical experience gained through internships or vacation work is a mandatory part of engineering programmes such as those provided by the selected case sites (UCT, 2015a, 2015b; Universität Bremen, 2013). Views from South African employers mirror those of the German employers (described thus far) in most ways, with minor deviations. For example, after emphasising the importance of a strong technical foundation and stating that she always assumes engineering graduates already possess technical skills, Claire White (SA) describes the ideal engineer as one who has a number of 'extras' in addition to technical excellence:

Beyond that, the perfect engineers or the ideal engineers are those that come with extra add-ons those are things to me like lateral thinking to be able to think out of the box, to be able to think in a slightly different direction. Those that have a bit of bigger picture, strategic thinking, and can think beyond what is currently the problem etc.

etc. and the other one that we do need a lot of is the soft skills: working with people, communication, etc.

She also comments on the type of thinking which is essential in the engineering profession, emphasising the need for engineers to think broadly enough to recognise the interconnectivity between problems and their solutions. She underscores this fact:

In the workplace, no problem is stand-alone. You need to understand its link to everything.

Paul Chambers (SA) points towards this in his description of the ideal engineer:

The ideal engineer needs to be one that is interested in developing solutions for society and doing that through the theory that is learnt at the university, but also through being very open and interested in learning to apply that theory in practice.

The translation or application of theoretical knowledge into practice was mentioned often, across the interviews. Sometimes, this concern was expressed in a way that suggests that engineering graduates are often unable to develop or express their curiosity about 'how things work' in the workplace. Pravesh Kumar's (SA) opinion shows this:

I think the ideal engineer is the guy who gets knowledge from the university but when he is in the environment of the work situation, he must be able to put that knowledge into practice. He must be able to ask the right questions, he must be able to want to know what's happening, how projects should be running, or how things should be working.

David Schrader's (GER) views are quite similar, but a noticeable difference lies in his reference to the rate at which technical knowledge becomes obsolete, calling for speedy learning and adaptation from engineers, to try to keep up with rapid change:

I think the most important thing for me is that he is always willing to learn because the science is constantly changing there is always new things coming on the (table) so you need to adapt to that. (...) [t]hen another important fact is not just heavy on theory- he must be able to implement that as well and must have knowledge about project management and contracts because that's the environment he is working in.

The environment in which engineers work is described as one that demands a myriad of soft skills that are applied in a range of contexts. Cindy Shaw (SA) expresses the concern that engineering graduates often have skewed expectations of the engineering profession or the work environment they might find themselves in upon completion of their studies. She suggests that engineering graduates often think all of their work will be carried out from an office desk. Although this may be a likely work situation for some, Cindy Shaw (SA) thinks that it is important for engineers to be willing and able to imagine their jobs outside of the office. The phrases 'out there', 'on site' and 'hands on' suggest that she values engineers who are pragmatic and eager to apply their knowledge outside the office. She also emphasises the importance of logic. In a way, she argues that when an engineer applies common sense to different dimensions of a problem ideally, this ought to result in the development of an innovative solution:

> *The way we see the perfect engineer is somebody who is hands on, who is out there, who engages with what's actually happening on site and who is able- from a very common sense point of view- to take what* he *sees and is able to come up with a better solution.*

Paul Chambers (SA) shares the concern that engineering graduates often have a narrow view of the field of work an engineer can be engaged in. This suggests that some engineering graduates are unable to recognise the potential of applying their knowledge beyond mainstream engineering projects. Again, it appears that the ability to imagine broad areas of application for engineering is limited, and it seems that Paul Chambers (SA) thinks part of the blame is on universities. He argues that engineering graduates:

> *[N]eed to get a very broad viewpoint of the engineering fraternity after the university. I think they (students) aren't always shown how broadly engineering is applied in industry. You know, an engineer can be working for a bank that underwrites a big project, and because of* his *technical skills-,* he *understands what the project is about and then* he'll *take a risk for the bank to provide finances for the project.*

Cindy Shaw (SA) also underlines this point, arguing that the unrealistic expectations of engineering graduates about their profession, leads them to have difficulties in abandoning their comfort zones. Below she describes the challenges of working on construction sites, stating that if engineering graduates lack exposure to site work from their studies, they tend to struggle to adapt to that sphere of the work environment:

> *If they haven't had that first and they get to us, it is really a huge challenge. Trying to get them to go through that personal development as well…from the shock of being on site- and that's often the reason they say they don't want to work on site because site is a very different and very difficult kind of environment. You're not with family, you can't go home to family, you're sitting in an environment out in the middle of nowhere, and the circumstances are tough.*

Other challenges related to personal development as a result of being or becoming an engineer are mentioned by Sebastian Braun (GER), who talks about the difficulty of figuring out one's role in society as an engineer. He explains that he has reached a conclusion about what it means to be an engineer, and states that he considers his purpose as contributing, in small ways, to improvement in society:

> *I would like to say something personally, which is about what actually helped me understand my place in work a bit better. I think it's all about…to make the world a little bit better. There is a need for improvement all the time.*

It is interesting to note that the employers (and lecturers and students) often refer to the purpose of engineering by using phrases such as 'solving problems' or 'fixing problems' or 'finding solutions'. These phrases dichotomise 'problems' and 'solutions' as if they are always mutually exclusive. In addition, the data carries the sentiment that engineers see themselves as problems solvers who have the potential, through their technical knowledge, to help fix societal challenges. Thinking about problems and solutions as mutually exclusive is problematic because it may result in overlooking the complexities that often characterise human challenges (like those prioritised in the MDGs and SDGs). Failure to perceive the interconnectedness of challenges such as climate change, poverty and inequality may ultimately result in the development of narrow engineering 'solutions' that do little or nothing to expand the capabilities of poor and marginalised communities.

Based on employers' views, the ideal engineer is someone who: 1) has a broad view of the engineering profession; 2) recognises the diverse contexts in which technical knowledge can be applied; 3) sees the interconnectivity between technical solutions and human well-being; and 4) has the ability to translate theory into practice, both in the office space and on construction sites. There is a consensus across both employer groups that one cannot be, at the very least, a good engineer without certain non-technical skills. These skills are discussed in the next section.

6.4 Valuable soft skills and transversal skills

The stand-out transversal skills extrapolated from the review of literature on engineering education (chapter 3) were critical thinking, ethical learning and cosmopolitan abilities (for example see Ahern et al., 2012; Boni & Berjano, 2009; Boni et al., 2012). The soft skills that stood out were team work and communication (for example see Riemer, 2007; Tonso, 2006). In order to verify the value of these skills in engineering practice, I asked the employers to comment on their relevance and importance, asking them how they may add value to engineering practice. In the section that follows critical thinking and open-mindedness, as well as communication and collaboration are discussed as non-technical skills that are most appreciated by the employers interviewed.

These results largely support reports on engineering graduate attributes (for example see ECSA, 2009; IEA, 2009) and findings from studies that focus on engineering graduate attributes and employers' perspectives (see Griesel & Parker, 2009). While these reports generally focus on the value of non-technical skills for employability purposes, my focus is on the relevance of these skills for public-good engineering. As such, the discussions that follow aim to present more nuanced understandings of the importance of soft and transversal skills by theorising about the instrumental and intrinsic value they add to engineering practice.

6.4.1 Critical thinking and open-mindedness

All interviewees expressed the necessity and importance of thinking critically about various aspects of engineering activities. The dangers of being an unquestioning engineer were often pointed out and the fact that engineers have a moral responsibility towards society was highlighted. Additionally, open-mindedness emerged as a prerequisite and dimension of being able to think critically. For example, Matthias Klemp (GER) likens critical thinking to taking the path less travelled in the sense that it often requires exploring and implementing unpopular solutions. He also implies that doing so requires fearlessness:

> *It is very important not to run in the path everybody is running (...) and sometimes you need to be brave (...) and to discuss topics which are non-topics, or nobody wants to talk about (...) because every challenge you have to look for all kinds of solutions even those solutions which seem to be far off or not explored solutions. So everything has to be brought up to the table and then to find the best solution.*

Matthias's words draw attention to some implications of thinking critically and they serve as a reminder that the value of critical thinking is diminished by being unable to verbalise critical thought. Vocalising unpopular ideas, exploring new terrain or bringing up issues 'nobody wants to talk about' requires confidence in the knowledge one has, bravery to use it and most importantly the ability to communicate critical thought effectively. The dangers of not being a critical thinker include failure to identify underlying reasons for unsuccessful optimisation of solutions, which may impede sustainable development efforts. Theodor Klein (GER) expresses this notion as follows:

> *Without it [critical thinking] there is no functionality, without that, you can't optimise anything and you can't improve.*

Based on this perspective, critical thinking is fundamental to engineering practice. Paul Chambers (SA) suggests that critical thinking also serves as a kind of moral compass for engineers, keeping them focused on their area of expertise and allowing them to make sound decisions that result in positive change, as society expects them to. He explains that without critical thinking:

> *They [engineers] wouldn't be in control of the work that they are doing. Because unfortunately there are a lot of people that don't stick to the facts and they [engineers] would be drawn into the hearsay assumptions which is not an engineer's area that they should be getting involved in. So critical thinking would ensure that they stick to the facts and as engineers, we're seen as being fair and transparent in our dealings, so to be able to do that you need to be quite critical.*

Thore Lehman (GER) emphasises the importance of being self-critical and his words remind us that thinking critically entails continuous questioning:

> *It's important. One must question oneself; question one's findings and the results that one is presented with (...)*

Theodor Klein (GER) expresses his opinion on critical thinking in a similar manner, also talking about the importance of questioning and the value of having a healthy degree of scepticism in order to avoid accepting information at face value:

Saying: "yeah okay I'll do it" without questioning, that can't be. One doesn't have to be overly pessimistic but one should be open and able to ask or inquire or question certain things so not just simply to accept, but to double check.

Similarly, Rolf Weiss's (GER) opinion is that critical thinking is also important for practising reasonable scepticism instead of always trusting the answers with which one is provided. He emphasises that:

Fundamentally, critical thinking is very important because one must really recognise the causes. So when one realises this hasn't been successful, one has to be able to critically ask, "why is this the case"? And not [accept things] just because everyone says it's not working.

Some interviewees understand critical thinking as being open-minded and showing openness to ideas or ways of thinking that are different to one's own and using that information as a basis upon which to make decisions. Matthias Klemp (GER) says:

I would describe it (critical thinking) more as openness: [To] be open for all ideas coming up, [and] then to evaluate and decide.

In this sense, openness can also be seen as a guiding principle that is fundamental for tolerance, especially when one interacts or works with people from diverse professional and cultural backgrounds. Matthias Klemp's (GER) words allude to the 'borderless' application of engineering solutions and the importance of the ability to recognise the often global and reciprocal impact of engineering to society:

Open-mindedness is very important- not to be focused on your local habits because we work in a networked world where it is very likely that the projects you're working on (...) may affect other parts in the world or are affected by other parts in the world.

Notions of openness and being able to see the bigger picture of engineering and its effect on society on a global scale resonates with Nussbaum's (1997) ideas on cosmopolitan abilities. Nussbaum argues that cosmopolitanism can be cultivated through education that stimulates capacities such as critical self-examination of one's own culture and traditions as well as empathizing with others and positioning oneself in another's place. Cindy Shaw's (SA) response indicates that the term cosmopolitan abilities is unfamiliar to her, because she responds by saying that cosmopolitan abilities are not essential. Yet, she adds:

> *Given that I say that, when it comes to working across borders, there needs to be a better understanding of world culture and an understanding of where that country is politically and socially, etc.*

Although awareness about the political and social conditions of a foreign country does not fully encompass cosmopolitanism, that level of awareness can be considered as a prerequisite of cosmopolitan abilities because one needs to be aware of the conditions surrounding another's life, before one can imagine themselves in that position. This kind of 'openness', as Mathias Klemp (GER) calls it, is also referred to as a tool to aid collaborative solution seeking. Below, Sebastian Braun (GER) talks about the value of open-mindedness in the engineering profession and relates this to developing engineering solutions that people have reason to value:

> *You can form, I think, a bigger group of people supporting your work if you are open minded (...). It's also important to know the expectations of the other colleagues you are working for or who you are producing results [for] and it's not just about that you are producing the result in your own way or you are just thinking this would be correct. You need to know the expectations of the others, so that you produce results that are of good use to them.*

That is to say, producing results that are of good use to people requires large degrees of openness. In capabilities language, creating valued capabilities through professional engineering functionings requires engineers to exercise cosmopolitan abilities.

The views described in this section suggest that engineers should be critically reflexive about a myriad of factors related to their occupation: the way in which engineering solutions are sought, the validity of the information presented to them, the reasons for failure to achieve optimal solutions and the value of engineering solutions to society. Openness and open-mindedness are closely related to critical thinking, and often described as prerequisites for it. The employers perceive the ability to be open-minded and practise openness to different ways of doing and being, as attributes that can foster creative thinking and enhance collaboration with culturally and professionally diverse colleagues. It is also evident that the employers see openness and open-mindedness as necessary for developing interest in how engineering activities affect peoples' lives on a global scale. In essence, the employers are talking about the necessity for engineers to be 'broad thinkers' who can embrace and critically evaluate different perspectives, values, and ideas in the process of developing engineering solutions.

The importance of openness is also reflected in the employers' views on teamwork. They all stated that engineering activities are mostly performed by project teams comprising of an array of professional groups and stakeholders. Therefore the value of being open minded or showing openness is seen as indispensable for developing the ability to interact effectively within and across engineering teams and with non-engineers. Because good communication entails being open to or receptive of the views of others i.e. people with different value sets, professional backgrounds, perspectives etc. communication can also be understood as an aid to collaboration. The next section discusses communication and collaboration as soft-skills that stood out from the data.

6.4.2 Communication and collaboration

Although the soft skill in question during the interviews was intercultural communication specifically (see appendix D), the interviewees spoke about communication more broadly, emphasising its importance in engineering in numerous ways. Matthias Klemp (GER) speaks of often having witnessed project failure because of poor communication and weighs the significance of technical competence against communicative competence saying:

> *(...) sometimes, someone who is not so strong on the technical side but who is a great communicator may be more valuable than the other way around.*

Sebastian Braun (GER) talks about the importance of communication not only in terms of engineers being able to communicate to various stake holders in a given project but also being receptive to information pertaining to how the results of engineering activities will be employed:

> *Communication is a very big thing (...) [it] enables you to know about the others' occupations (...) [and] to know what other people do with the result of your work.*

With this statement, he foregrounds not only the value of being able to communicate effectively, but also the need to know what happens to engineering products once they have been successfully designed, manufactured, or constructed. He puts forward that it is crucial for engineers to have a holistic view of the effects of their work on society, implying that their work as engineers does not end once a particular product is complete, but continues long after the product is in the hands of the end user. Also, we are reminded here that although concerns about engineers' poor communication abilities are mostly centred on them failing to 'send' the right message effectively, it is equally important for them to be active 'receivers' of information.

Perhaps one of the biggest disadvantages of poor communication for the engineering profession is the diminishing effect it has on their effective power. Matthias Klemp (GER) expresses his concern over this saying:

> *Engineers tend to be in their cocoon of technology and [tend] not to go out. So sometimes, they have a lot of force but they cannot bring the force to the world.*

The ability to 'go out' and bring 'the force to the world' triggers thoughts about agency. As discussed in chapter 1, agency is the capacity to initiate action through formulating valued aims and beliefs, and it requires mental health, cognitive skills and opportunities to engage in social participation (Alkire, 2002). As Sen (1985) points out, there is a profound complementarity between individual agency and social conditions and it is therefore important to acknowledge both the centrality of individual freedom and the strength of social influences on the extent and reach of that agency freedom. Looked at through the lens of the capability approach, the inability for engineers to bring their 'force' to the world, indicates that there are conversion factors that restrain engineers' agency achievement. That is, there are conditions that get in the way of engineers' capacity to use their effective power.

This line of thinking led me to wonder: What are these conditions? How can they be overcome? What can engineering education do to enhance graduates' agency? These questions resulted from thematic coding of the data, coupled with thinking about the significance of the answers from a capabilities perspective. They reflect my thought process during much of the analysis procedure, especially when reading parts of the transcripts that were coded 'agency' and 'voice', and I found it interesting that these were often sections of the interview where communication was the main topic. Ultimately, this led to a more nuanced understanding of communication, and recognising how ineffective communication can signal diminished agency. For example, Claire White (SA) talks about the necessity for graduate engineers to be able to communicate assertively and eventually take on leadership roles within the workplace. She suggests that some engineering graduates struggle to acquire these abilities due to cultural upbringings that emphasise obedience to senior members of one's community:

> *For instance, somebody who is culturally brought up to 'obey your parents', 'obey your teachers'- you then want (that person) to stand up in a meeting and say "no no no, this is my idea, this is what I want to do, this is what the plant needs" and persuade other people (...) but if you keep quiet, we're missing something. So the entire solution will be deficient because you haven't added what you need to be adding.*

Cindy Shaw (SA) expresses a similar concern giving the example that cultural principles such as respect for elders may have a negative influence on engineering graduates' assertiveness in the workplace. She says that some graduates:

> *[D]on't want to push, out of respect, frequently. They don't make the kind of noise that is required to get senior management attention...and then you end up with sometimes critical things [problems] on site.*

At this point, it is interesting to note that concerns about engineering graduates' inability to communicate assertively are only mentioned by South African employers, both of them women. As described in the employers' profiles provided at the beginning of this chapter, the two women amongst the selected group of employers both work in the human resources departments in their companies.

While Claire White (SA) is a qualified chemical engineer who is involved in the recruitment, training and development of young graduate engineers at Sasol, Cindy Shaw (SA) holds an organisational behaviour doctorate and heads the graduate recruitment, selection and development unit of Group 5's bursary division (see table 6). As such, Cindy Shaw is the only non-engineer amongst the employers. Her views are therefore unique because she has specific and extensive working knowledge of the attributes, values, and skills that are valued by the company she is employed in. She also has direct interaction with engineering graduate recruits while they are fresh out of universities and is in a unique position to observe their development due to her involvement in the graduate training programmes. In comparison to the men's responses, at times Cindy Shaw's responses offer more nuanced accounts of some complexities that characterise communication in South African engineering firms. It is likely that due to Germany being more culturally and somewhat more racially homogenous than South Africa, these complexities may have been more difficult to observe in German work environments. Cindy Shaw's (SA) views on the interplay between race, gender, age, cultural norms, and communication in a South African engineering firm are discussed in section 6.5.

David Schrader (GER) attributes a significant number of project failures to the inability to speak up:

> *[It] doesn't help you to be full of knowledge if you can't talk to anyone or you can't convey your message. And from experience in projects, all the projects I have been working in, if there was problem, it could be always related to communication problems. So that's a very important thing. And also, since you are not alone in the world you need to be able to deal with people, other human beings, ne? You often have the tendency that an engineer is a good designer but he can only relate to himself on his computer and he is not really discussing [things].*

David's (GER) words that one is 'not alone in the world' and that one needs to be able to deal with 'other human beings' articulates concern about engineers who narrowly apply their technical knowledge to a specific task in isolation, in contrast to sharing and developing their ideas with diverse stakeholders. Examples of such stakeholders are communities on the receiving end of development aid that is planned, designed, and/or constructed with the significant contribution of engineers. For example, Sebastian Braun (GER) complains about the often-limited communication between engineers involved in development aid projects and the individuals or groups for whom the aid is intended. He explains:

> *If you do projects for communities like, I don't know… bridges and houses- you have to find a strong acceptance within the community. If you realise projects without public acceptance, then it's going to be very problematic (...) it's important to get everybody within the boat to make the decision.*

Top-down planning, which fails to engage communities as co-researchers and co-planners who can collaborate meaningfully with engineers, may result in the creation of artefacts that do not create valued opportunities. Developing engineering solutions that result in enhanced capabilities for society requires engineers who recognise the "limitations in the 'universalistic' notion that technology can be transferred from one context to any other without regard for socio-cultural, political, economic, and other systems that inform and are informed by community identity, values, and aspirations" (Schneider et al., 2008: 313). For this reason, it is important to strive towards the ideal to 'get everybody on the boat to make the decision' as Sebastian Braun (GER) put it.

On the other hand, Paul Chambers (SA) warns not to over emphasize the importance of communication skills. In the excerpt below, he argues that communication skills are only relevant to half of all qualified engineers:

> *They're important to about probably fifty percent of engineers. Fifty percent that choose to go into a design/consulting kind of area where the product of their work is a calculation or drawing or specification…the lesser the softer skills [necessary]. The ones that go into project engineering-which is the execution side of engineering that deals with suppliers, contractors, clients, government bodies-need to have people skills.*

I did not expect a response like this from any of the interviewees and was therefore surprised by it. It shows that there is no necessary consensus amongst the employers about the importance of soft skills in engineering practice. In addition, this response indicates that communication skills are applied to various degrees, depending on the type of engineering work one does. Nevertheless, the views of all employers do confirm that engineers' work, although highly technical in nature, is rarely devoid of human interaction, which usually takes the form of teamwork. For example, Sebastian Braun's (GER) says:

> *Most of the time it's team work. It's working in a group and you need to know that you are just one part of the big picture and you are supporting something. It's not all about you and your job…it's never just what you do-it's always part of the big picture.*

In thinking about the bigger picture and what that means for engineering teamwork, and how engineers might position themselves in these teams, I began to think about teamwork in much broader terms. In the broadest sense, 'engineering teams' include individuals, community groups, and different clusters of society whose capabilities are shaped by the processes and results of professional engineering activities.

To summarise, findings imply that the complexity of engineering challenges necessitates team-based solution seeking. What has perhaps been overlooked in bringing this message across is the complex nature of the 'team'. What is often described as 'team work', I refer to in these findings as collaboration i.e. team work not only in terms of engineers working with architects, technicians, quantity surveyors and contractors on a particular project; but also teamwork as community engagement. In other words, collaboration and communication between engineers (and other industry stakeholders) for the purpose of creating development solutions that help expand the capabilities of designated communities. In this sense, collaboration is both a means to and an end of communication, which can refer to, but is not limited to, activities such as:

- The exchange of ideas in the workplace amongst fellow engineers;
- Receiving and critically assessing instructions from senior managers;
- Consulting with stakeholders or communities to generate valuable solutions; and
- Being knowledgeable about how engineering products are used by, and affect the end user.

The terms ‘communication’ and ‘team work’ are therefore understood here in a broader sense as being synonymous to or necessary for collaboration involving engineers and any group of people who are affected by engineering outcomes.

What emerges clearly from the interviews is that technical excellence alone does not signify an excellent engineer. The characteristics of the ideal engineer described by the interviewees in the early part of this chapter suggest a vast number of non-technical capacities that employers would like to see in engineering graduates. Aside from a solid foundation (in mathematics, science, and engineering sciences etc.), the aptitudes desired by the employers interviewed were discussed under the three Cs namely: communication, collaboration as well as critical thinking and open-mindedness. These non-technical skills have value and relevance for the engineering profession not only in terms of potentially improving engineering graduates’ capability for employment, but also with regard to developing engineers who are positive social change agents in society.

6.5 Gender nuances

The conclusion that can be drawn from a brief look at literature that explores issues of gender in engineering (see chapter 3) is that engineering education research must find ways to foreground and celebrate heterogeneous understandings of engineering and heterogeneous engineering identities (Faulkner, 2007). Faulkner (2007) provides two strong reasons for this. First, every aspect of engineering is heterogeneous; even the most apparently technical roles have social elements embedded inextricably within them. Second, foregrounding and celebrating more heterogeneous images of engineering can only serve to make the profession more inclusive (Faulkner, 2007). In an attempt to promote a heterogeneous image of engineering, and consider the relevance of women’s perspectives for public-good engineering, this section pays specific attention to one woman's perspectives that stood out from the employer interviews.

Cindy Shaw (SA) shares her insight on the differences between male and female engineering graduate recruits. She suggests that the resilience of female graduate engineers often makes them stand out from their male counterparts. She believes that women's resilience is developed throughout university learning and she argues that it is strengthened in the workplace because they have to fight to prove their worth in a male dominated industry. She says if female engineering students:

> *(...) survive all the way through and actually graduate- we find that we get them on site, and this is where sometimes- it knocks their confidence and they struggle a little. But on the other hand, you'll have the exact opposite experience with- and this is the more common experience- that if they've been through the hard knocks at the university, the women on our sites really thrive and they end up in management positions…sometimes even faster than the guys [do]. Because they've had to fight in a male dominated environment, you see.*

Cindy Shaw (SA) speaks of female engineering graduates' confidence and willingness to participate in non-compulsory training and development exercises offered by Group 5. She says that this is a noticeable difference to male engineering graduates and her words suggest that female graduates are more prepared to take initiative and lead:

> *So that's why you see even at our summer camps that we have within the organisation they're the ones [female graduates] who put their hands up first, they're the ones that are engaged with all the activities. And their management skills are usually a lot better [than the males] and so that works for us very well.*

She identifies some challenges for female engineers, citing difficulties for senior, white, male engineers to accept young women engineers in the profession. Difficulties are especially mentioned with regard to the challenge of learning to accept women in engineering, particularly in their capacity as managers. Her response implies that these challenges form part of the experiences that can actually enhance female engineers' agency:

> *The challenge however is older white guys who have been around a long time- on site- nobody told them yet that they need to evolve and accept women as managers and so sometimes that's where a lot of the challenges are. But over a very short time,*

we find that those issues work themselves out because women are better attuned. They're able to-like for example with our older black supervisors-they are able to show the right level of respect to them and that kind of thing. So it's a good and bad side of things but it teaches confidence and assertiveness that they need.

Cindy Shaw also shares her insight on behavioural differences, as she has observed amongst the female engineering graduates, attributing these dissimilarities to race and cultural factors that can inhibit black women's capability for voice. Her view suggests that the cause of this problem lies in the existence of patriarchal cultural norms that govern African traditions, which discourage black women from assuming positions of superiority over men in the workplace:

(...) if you want me to generalise there, white women tend to be a lot stronger and when I say stronger I'm talking about from a personality point of view. So this is something that we need to work on in our black ladies- that they can speak to an older black foreman and actually tell them what to do. That, from a kind of cultural perspective, is sometimes a little bit more difficult.

After explaining that it was difficult to generalise due to the low number of female engineers in the company, I asked her if it was difficult to fill vacancies with female graduates. She replied that it is becoming easier, but that more has to be done to make engineering an attractive profession for women, starting with the promotion of math and science subjects in schools. She believes that women do not tend to be interested in engineering because:

I honestly think it's still rooted in the way we grow up- that women are not given as much encouragement around maths and science and that's where our biggest problem is.

As mentioned earlier, some findings were unique to the South African views and this section has shown how Cindy Shaw (SA) specifically mentions concerns about cultural norms that impede on assertive expression by engineering graduates in the workplace; no such concerns were shared by the German employers. In addition, resilience emerged as an important attribute from Cindy Shaw's (SA) perspective, where it was highlighted as a trait that ultimately enhances female graduates' assertiveness, confidence, and agency in a male dominated industry.

Having discussed employers' perspectives on the characteristics of the ideal engineer as well as the relevance and importance of transversal skills in engineering practice, the discussion turns to employers' views on questions related to the links they perceive between the work engineers do, its influence on societal development and its role with regard to sustainable development. Drawing from these views, the next section provides a theoretical, but empirically informed vision of public-good engineering education.

6.6 Public-good engineering

There is general agreement amongst the employers interviewed that the work engineers do contributes to positive change in, and valuable benefits to, society as well as sustainable development. However, there are mixed views on the effective power of engineers to be drivers of this change.

Rolf Weiss (GER) shares his wide-ranging view on the interrelations between engineering and human development, reflecting on the fact that a joint and collaborative movement towards sustainable well-being requires the participation of stakeholders at the economic, political, societal and individual level. He argues that engineers play an important role in advancing sustainable development but acknowledges that this is not unique to the engineering profession. He also elaborates on this view by adding that the results of the work engineers do in relation to technological advancement are often the starting point to instigate sustainable development efforts:

> *Engineers can be part of the solution. Because there are questions of power supply, water supply, the fundamental problems that when you look at things globally, the human race has- [is] of course dependent on good technical solutions. That on its own is not enough, because it needs political conditions, it needs financing, and so forth but new technical solutions could be the initiators to ensure that solutions are found and in so far, it is a very fundamental and important role that engineers play, especially for such questions as sustainable development…and the challenges are many.*

On the contrary, Matthias Klemp (GER) is less keen to say engineers have effective power. His words show a more critical stance to this assumption where he, for example, talks about the role industry plays in dictating engineering activities saying that some companies, including engineering firms, only support pro-sustainability initiatives as a front and that:

they make little projects for advertisement to show that they are 'green' but finally what they would like to do- they would like to earn money and they don't care (about sustainability.

His depiction of engineers gives the impression that they are more responsive to the demands of industry, rather than them being initiators of positive social change. His views on the role of engineers in promoting sustainable development agendas are also not enthusiastic, he posits that the influential power of engineers is limited, stating that:

Engineers have influence of course. But I think one should not overestimate this influence. Politics has much more influence.

Additionally, he goes on to conclude that:

Engineers do not change the world basically.

Matthias Klemp's (GER) opinion is particularly sceptical, and elements of his statements are supported by the views of other employers. On the contrary, Sebastian Braun's (GER) view is more balanced. He affirms that decisions made by engineers in judging the feasibility of construction projects are indicative of their strong position in society and in matters of development. He also speaks broadly about all types of employment being linked to human development:

What everybody is doing for his living I think is about the increase of life quality. And it is- if you are aware of this- I think you become aware that it's not so much about quantity or increased quantities, it's about increasing of quality. And for the engineers the relevance is that during a feasibility phase of projects (...) it very much depends on the engineers. They are, in most cases, bearing the decisions whether a project is going to be realised or not, and it's a big responsibility.

Thore Lehman (GER) sees the role and responsibility of engineers with regard to development and sustainable development in a similar way. He points out, that engineers have to evaluate the conditions and economic aspects of construction projects, and that it is ultimately engineers who ensure the implementation of development projects worth pursuing to achieve positive change in society. Theodor Klein (GER)'s view corroborates this:

We get to talking about renewable energy where the energy that is created from power plants can be reused, and we can generate clean energy. That can only happen *through a vision in which we continue to question and continue to develop research and simply to keep going in the direction (...) to ensure a more secure source of power.*

Claire White (SA) expresses concern that engineering graduates believe the only way in which they can meaningfully contribute to sustainable development is by being employed in companies that are in the renewable energy sector. She stresses that during her selection interviews she brings it to the attention of the individuals being recruited that they ought to look at other avenues to make meaningful contributions to society through their work, regardless of the engineering discipline or field:

We have a lot of engineers who say they want to get into environmental engineering and I kind of tell them that every engineer should be thinking about environmental or sustainable development, whatever you do- every project, any way you run a plant… it's your responsibility.

Paul Chambers (SA) sees this similarly, saying that he thinks engineers are integral in the development of society's growth:

Be it roads, schools, houses, hospitals, power stations, you know- the employment of people in society and providing society's infrastructure so that society can grow and in the end have a better lifestyle.

He goes on to provide an example of how engineers can design effective solutions to societal challenges in a manner that improves not only the infrastructure in a particular community, but also equips community members with useful skills. Through this, he alludes to community capability expansion through public-good engineering, where the results of engineering efforts e.g. designing a dam, result in creating valuable capabilities e.g. skills that enhance capability for employment. In his example, he discusses a construction project where the engineering team that designed the dam specifically aimed to ensure that it would require community involvement. This is also a good example of what one might refer to as a participatory approach to development aid:

What the engineers are doing is that they're designing a dam so it can be built by eight hundred people. And those eight hundred people are learning skills and hopefully those skills will be used to build other dams, maybe not a dam as big as this one because it's quite a labour intensive construction project, but build maybe other *farm dams and that skill then gets kept. Whereas traditionally it's been like we go somewhere, we go build something, and come back (...). [B]ut now it's more about the sustainability of that community as well, which is quite cool.*

Cindy Shaw (SA) discusses some of complexities of such efforts by engineers, where she is candid about the benefits of these approaches for the engineering firms that make use of them. She also signals the importance of processes of deliberation between representatives of the firm and community members over the engineering activities being instigated. Historically, rural communities have often been displaced from their homes for the sake of 'development' efforts, efforts pioneered with the significant contribution of engineers, but minimal to no regard for meaningful community engagement (Lucena & Schneider, 2008; Schneider et al., 2008). Below, Cindy Shaw (SA) provides an example of how modern approaches to development efforts have improved:

Some of these more remote places, we make sure that we understand who the community is before we get there and when we engage with them we appoint community liaison officers and we look at growing the actual competence of the people in that area through short skills programmes etc. so that we can employ people. And we can't say it's just because we are marvellous people, but we do it for very pragmatic reasons, we want labour close to where we are working but we also want to make sure that we've got good relations with these people around as well. So I think you can never take the pragmatism from an engineer but there is also that willingness and the aspiration to contribute to a better society because otherwise they wouldn't be doing the jobs that they are doing. And yes, of course they do it for money, but I think the engineers we work for have a very holistic perspective.

She concludes her response by adding that engineering is about improving society, and argues that there is a keen awareness amongst engineers that all engineering accomplishments affect communities. She argues that this is part of what fuels the intrinsic desire some individuals have to become engineers and says such individuals have a:

very keen awareness that that's what the job is about and that's part of their kind of 'calling[31]'.

[31] It is interesting to note that the German word for 'occupation' is *Beruf*, which stems from the word *Rufen*, meaning 'to call'.

Interestingly, some interviewees expressed concern about the necessity for engineers to know their ‘limits’. Rolf Weiss (GER) speaks of his concerns regarding the notion that human beings and engineers in particular, generally assume a position of superiority over the environment. He argues that doing so often obstructs engineers from acknowledging the limits of imposing technical solutions to human challenges. He says:

> *But when I’m dealing with technical skills, it’s important for me to really understand the limits, yeah? Why does this technique no longer function in this section? Where are the limits of technical possibilities? What is the reason why we can no longer build without limits? To really understand the limits is for me a very important foundation that engineers should know as a basis. So what is important is not only to know what is being practised today, to take on the doable. Rather, when solutions are being searched for one must have understood why. When one thinks across these things you must recognise why the boundary is actually there that [has] led to the inability to build X in that dimension.*

He continues to explain that technical knowledge in itself is limited in applicability because of ever-changing problems that require engineers to come up with new ways of thinking and different approaches to solution seeking:

> *I believe that in the purely technical knowledge, firstly-it is very inflated, because in fact, that knowledge is permanently new. We are living in an age where at the end of your study programme what you learnt at the beginning of the programme is almost already outdated. That which has permanent value though, are other capacities that one always needs: how people work together, how people find solutions together…those are the fundamental things.*

By reflecting on the limits of technical solutions to human problems, Rolf Weiss (GER) brings our attention to the importance of transversal skills and the values that underpin them. He stresses that they outlast technical skills in terms of their relevance in society. He points towards the idea that the way in which solutions are brought about, although based on technical expertise, have to be merged with other forms of knowledge and principles to achieve sustainable human development. Some examples of different forms of knowledge specific to engineering are discussed in the coming section related to what universities can do better to impart such knowledge.

To summarise, the views expressed in the interviews suggest that engineers do indeed have the power to influence decisions on projects that are geared towards conceptualising and implementing effective and efficient solutions to a variety of human development challenges. Being in possession of impeccable technical skills and knowledge plus transversal skills such as those discussed in section 5.4 constitutes some of the characteristics of the ideal engineer, who would typically try to act in the interest of sustainable human development. However, some responses suggest that the true authority in this matter lies at the corporate level, where *homo economicus* principles guide business activities to prioritise exclusive economic profit over inclusive human development or environmental well-being.

Based on my interpretation of the employer perspectives (see summary of findings in table 12) which I look at through a capabilities lens, public-good engineering could be defined as engineering that:

- is founded on principles of *homo reciprocans*[32] rather than *homo economicus*;[33]
- seeks to expand capabilities and enable valued functionings for (poor) communities;
- meaningfully engages with such communities, to ensure that engineering accomplishments benefit them in ways they have reason to value; and
- is not carried out with disregard to the environment and acknowledges the boundaries of human influence on it.

Lucena and Schneider (2008) state that since the relationship between engineering and development began to take shape, engineering work in local communities has been 'top-down,' meaning that the planning, design, development, and implementation of projects have been done mostly without consultation with the people that the projects are supposed to serve. This attitude toward local and indigenous communities has been reinforced by the ideology of modernisation that has motivated most development work since the 1950s (Lucena & Schneider, 2008). Recognising this problem, social scientists and development critics have been advocating participatory practices since the 1980s, and promoting meaningful participation and equal partnership with communities instead of treating them like passive recipients of development (Lucena & Schneider, 2008). As Lucena and Schneider (2008) warn, sustainable development projects that do not shine a critical, self-

[32] Seeing humans as cooperative actors who are motivated by improving their environment
[33] Seeing humans as narrowly self-interested agents who are primarily concerned with meeting their subjectively-defined ends optimally

reflective light on their work may risk replicating traditional development projects that often disempowered the communities that they were meant to serve.

Schneider et al. (2008) contend that projects laying claim to sustainability often ignore key components of long-term, intergenerational meaningfulness by ignoring significant community involvement. In engineering education, students involved in sustainable development projects are rarely offered substantial theoretical, historical, or practical education in development studies or community interaction (Lucena & Schneider, 2008). So, although engineers may play an important role in development projects, their training is often limited to technical problem-solving approaches; approaches that may lead to the types of failures resulting from the fact that engineers 'plan and organise everything themselves' instead of truly engaging with the communities they aim to help (Schneider et al., 2008). Based on the four dimensions of public-good engineering outlined earlier, public-good engineering is opposed to practices that do not expand communities' valued capabilities and functions and it acknowledges the importance of community engagement. As such, adherence to these dimensions of public-good engineering could minimise the types of failures identified by Lucena and Schneider (2008) and Schneider et al. (2008).

The four dimensions of public-good engineering are considered in relation to the views of lecturers and students in chapters 7 and 8, to substantiate their validity from a higher education i.e. university stand point. That is, lecturers' opinions on the ability of universities to advance these dimensions in their engineering programmes through pedagogy and curriculum are discussed in chapter 7 and students' perceptions of their own ability to practice public-good engineering upon completion of their studies are looked at in chapter 8. The penultimate segment of this chapter thus looks at questions related to what universities can do to equip engineering graduates with capacities that enable them to function as public-good professionals.

6.7 What can universities do (better)?

The employers often criticised universities for failing to equip graduates with broad perspectives of what professional engineering can look like in praxis. Paul Chambers (SA) shares his thoughts on this matter as follows:

> *I don't think they (engineering students) get given always enough insight into how broad it is so when they make a career decision to go and work in a company in South*

> *Africa they either decide to go and work for a consultant or for a contractor but they don't see anything in between and that's a pity. So what can universities do more? I don't know if it's still being done- but invite the industry to source the engineers, and while they are sourcing, get the industry to explain what they do in engineering. So while they give bursaries let them give a lecture on what they're doing in that company. So they'll get their bursaries to students but at the same time, they [students] get to see what the rest of the industry is doing.*

Pravesh Kumar (SA) also expresses concern about the disconnect between what engineering graduates expect and what happens in practice, attributing this disconnect to the fact that engineering educators usually have little or no experience in working as engineers and therefore lack the ability to impart appropriate visions of what it means to be an engineer in industry. He concludes that the role universities can play in enhancing transversal skills is limited and he feels that practical work in industry may prove to be the better 'teacher' in this regard:

> *I think it's more learning on the job…because ninety percent of the time you find that the guys that are actually in lecture rooms or the lecturers, the professors have not worked in the real world itself. They have excelled in what they were doing and they continue with their studies there to become professors, but never really work in an environment like this (Sasol). And as a result of that what advice are they supposed to give a student who's now going to [that] environment? They would not be able to.*

David Schrader (SA) also acknowledges the difficulty for engineering educators to impart transversal skills through their actual teaching practices, saying that it is much easier to teach content which is regurgitated in exams versus instilling principles of autonomy of thought or developing students' agency. He says that engineers should be taught to synthesise and analyse information in a manner that is conducive to independent thinking. In addition, he stresses the difficulty in doing so, and argues that it is the reason behind teaching approaches that encourage rote learning. He says:

> *It's a bit more difficult on the teacher's side (...) it's challenging. So they [engineering lectures] just give something for the kids to chew on, and then let them repeat it in writing a test or so.*

Asked if they thought the inclusion of humanities content in engineering curricula might aid the development of transversal skills, all the employers agreed that this would be helpful. David Schrader (SA) advocates the inclusion of 'general studies' being a good initiative. He also shares what stands out for him when making decisions about selecting graduate engineers in his company:

> *The engineer should remember there is a society with real human beings, not so? What I think could help as well for these kinds of things...what we call 'Studium Generale*[34]*'. So that means sort of voluntary subjects you can choose as an add-on to your mandatory curriculum. And on the employers' side if I do an interview with a candidate the most important thing for me is not his standard curriculum, there are hundreds with the same curriculum and maybe even hundreds with the same results (grades). That doesn't tell a story to me at all, it just explains is that a person can handle his subject matter. The most interesting part is what he is doing or what she is doing over and beyond the standard curriculum. That is what tells a story where you see okay, that's a very engaged student, he is working beyond the necessary, beyond the mandatory, he is doing things on his own.*

Rolf Weiss's (GER) response on the integration of humanities subject matter into the engineering curriculum is more complex. He speaks of the relevance of the humanities for all study programmes alluding to the idea that knowledge gained from the humanities is more sustainable than technical knowledge which has the potential of losing value over time because processes of design, construction etc. are ever changing. He explains this by contrasting foundational physics knowledge to knowledge of technology design and then links this to transversal skills:

> *That means what one really needs, of course aside from the technical foundation, because those basic foundational technical competences will also always remain, the real technical foundation like Newton's laws will remain, or the Law of Relativity, but technology, how one constructs a circuit board was different twenty years ago with SMD technology, then ten years later and then today(...) it has a very short life span this kind of knowledge; but how people work together, how people find solutions together, those are the fundamental things.*

[34] *Studium Generale* is the German phrase for General Studies

Rolf Weiss (GER) is the only interviewee to direct his attention to engineering educators in his responses, reflecting on pedagogical practices he finds inspiring. He encourages approaches to teaching that focus on highlighting the interconnectivity of various elements of engineering functions:

> *I always find it admirable when the lecturers in a university (...) also engage in practical work, and that means something like: okay we're going to build a computer out of limited parts that we have to work with. How can we find an optimal solution? Exactly these types of questions should be linked or related to management tasks. I believe for example that when all semesters entail something like that: organising seminars, taking over organisational responsibility for something during the semester…and to relate such tasks with the theoretical approaches, would really teach a lot.*

When asked if he had any concluding comments at the end of his interview, Rolf Weiss (GER) replies that the biggest area where universities are failing in terms of educating engineers (and other professionals) is imparting lasting or universal human values:

> *We're living in exponential times. And the changes are so huge that we have to ask ourselves where are the real ground values that always remain? That is what I find crucial; which is really valuable but is not really being disseminated in universities. That's the most essential thing.*

The employers' perspectives suggest that universities can aid the cultivation of engineers' transversal skills through pedagogical practices and curricula in engineering education that explicitly address outcomes in relation to 'know that' or propositional knowledge, and 'know how' or procedural knowledge. A third form of knowledge may thus be needed: know why. Know why, could be defined as ethical knowledge that is concerned with 'the right thing to do' or values that underpin approaches to, or motives behind engineering. That is, values that underpin pro-poor engineering or human-centred engineering or public-good engineering etc.

Through my interpretation of the responses provided across all sections of the interview, I have defined public-good engineering as engineering that, amongst other things, authentically considers the capabilities of communities, especially poor communities, and aims to secure valued functionings for them through engineering endeavours.

Based on the findings of this chapter, such an engineer would (beyond having impeccable technical skills) have the capacity to exercise critical reflexive thought, practice open-mindedness and use communication as an aid to collaboration for public-good engineering. This is summarised in table 12.

Table 12: Summary of findings from employer interviews

The ideal engineer	Valuable skills	Dimensions of public good engineering
Has a broad view of the engineering profession	Critical thinking	Founded on principles of *homo reciprocans*
Recognises the diverse contexts in which technical knowledge can be applied	Open-mindedness	Expands (poor) communities' capabilities and functionings
Sees the interconnectivity between technical solutions and human problems	Communication	Meaningfully engages with communities to ensure that they benefit from engineering outcomes
Has the ability to translate theory into practice both in the office space and on construction sites	Collaboration	Carried out with respect to the environment

6.8 Summative discussion

With regard to what attributes characterise the ideal engineer, the responses showed little or no deviation from the message conveyed in literature: that engineering knowledge and technical expertise have to be complemented by transversal skills, soft skills, and humane values. The general sentiment of the employers' responses is that universities sometimes fall short in providing realistic expectations or understandings of the engineering profession. Reasons for this include the idea that there are not enough opportunities for meaningful practical work during engineering studies, or that university lecturers themselves have no personal experience in the world of work and can therefore not relate this experience in their teaching. The employers' views therefore imply that more dialogue that is meaningful needs to take place between universities and industry, concerning how students understand engineering theory and how and where they can expect to practice engineering. On the other hand, the employers seem satisfied with the technical skills engineering graduates are able to bring with them from the university. The role of industry to further graduates' development is seen as crucial because it is in this space that they gain meaningful experience of the actual day-to-day activities of engineers.

The interviewees provided some examples of the type of measures that can be taken by universities to broaden engineering education outcomes so that graduates are better equipped with the kind of transversal skills they would like them to possess and apply. The recommendation most frequently provided related to the need for curricula in engineering education that addresses outcomes in relation to propositional and procedural knowledge for example through the inclusion of humanities courses.

Only once, were the teaching practices of engineering educators brought to light, with the suggestion that lecturers ought to develop engineering pedagogies that strive towards magnifying the interconnectivities between engineering functionings and human capabilities. This type of knowledge relates to non-technical skills such as critical thinking and open-mindedness, communication and collaboration, which were identified as the type of skills that could be conducive to public-good engineering. As such, what matters in the education of engineers is not only what they know, but also how that speaks to how they apply that knowledge and the extent to which they apply it in the creation of products that add value to the lives of the poor, and the lives of current and future persons.

Responses that were particularly distinctive relate to gender and cultural aspects that emerged from the interviews of the only two female interviewees. I also highlighted the gendered language used by some employers, who consistently referred to engineers as male. This affirms (as pointed out in chapter 3) that, when thinking about engineering, a *man* is imagined as 'the engineer' despite the growing numbers of women in engineering industries.

Despite the dissimilarities of education structures, university education, and socio-historical characteristics etc. between Germany and South Africa (discussed in chapter 2), employers' views presented in this chapter proved to be similar. There were however some salient differences. For example from the South African female employers' responses, gender and culture were identified as potential negative constraints for assertiveness, whereas no such mention was made by neither the South African nor the German male employers. It is important to note that I did not pursue the aspect of gender and culture in the interviews and focus group discussion. Instead of imposing these aspects into the discussions, I wanted to see if these themes would emerge from the data i.e. I did not explicitly ask them to comment on issues of gender (or culture or race), but I was open for the discussion to go in that direction if/when these issues did come up.

Chapter 7

Lecturers' perspectives on teaching and on engineering education

7.1 Introduction

The results reported in this chapter are based on findings from 10 semi-structured interviews conducted with lecturers from the University of Cape Town (SA) and the Universität Bremen (GER). These interviews were carried out between March and August 2014. Similar to the presentation of the findings in the previous chapter, my discussion draws substantially on the voices of the lecturers, with their answers interjected by summaries of my interpretation of their responses. These summaries also link the selected interview excerpts by contextualising the quoted words in order to make clearer, the connection between the interview data and the conclusions I draw from my analysis of it. This chapter also weaves relevant secondary literature through the empirical data. This approach works to highlight the alignment of the lecturers' perspectives, with recommendations from international literature on engineering education reform. Starting with introducing the interview participants, the chapter then discusses the value and purpose of engineering education, before unpacking the different types of knowledge or ways of knowing that are considered as indispensable to public-good engineering education. Thereafter findings are presented on what the lecturers thought they could do to teach non-technical skills. This is followed by the summative discussion that concludes the chapter.

7.2 Introducing the lecturers

At the time of the interviews, most interviewees were experienced academics within the Faculty of Production Engineering at the Universität Bremen or the Faculty of Engineering and the Built Environment at the University of Cape Town (see summary of profiles in table 13). As the following individual profile summaries show, all interviewees also serve/served as head of an engineering department or research group at their respective universities:

7.2.1 German lecturers

1. *Prof. (em.) Dr.-Ing . Jan Bremer* is an honorary professor of Applied Mechanics. His career in teaching and research spans across institutions such the University of Karlsruhe, the Technical University of Berlin and the Technical University of Clausthal where he taught in

the areas of Fluid Mechanics, Thermodynamics, Systems Engineering and Technology Assessment.

2. *Prof. Dr.-Ing. Andreas Kleid* heads the Department for Integrated Product Development at the Faculty of Production Engineering at the Universität Bremen. He offers courses including Introduction to Engineering Design, Applying and Comparing Creativity Techniques, CAD Management and Virtual Product Development as well as Production Systems.

3. *Prof. Dr.-Ing Antonio Marco* is dean at the Faculty of Production Engineering at the Universität Bremen and heads the Hybrid Materials Interfaces (HMI) Research Group within the Department of Process Engineering. The courses he teaches include Foundation of Materials Sciences, Photovoltaics, and Biology for Engineers.

4. *Prof. Dr. Dr. Jonas Schneider* is an honorary professor leading the Vocational Education and Training Research Group at the Faculty of Physics and Electrical Engineering at the Universität Bremen. An expert in the field of vocational training research, his current projects also include extensive comparative education research involving countries like Germany and South Africa.

5. *Prof. Dr.-Ing. Maria Schwartz* is a director of the Bremen Institute for Mechanical Engineering, within the Faculty of Faculty of Production Engineering at the Universität Bremen. Heading the department of Design and Process Technology, she teaches courses such as Assembly Technology and Systems, Process Planning and Assembly Logistics.

7.2.2 South African lecturers

1. Prof. Chad Block is associate professor at the Faculty of Engineering and the Built Environment in the Department of Chemical Engineering at the University of Cape Town. He is a senior lecturer in chemical engineering and head of research in Environmental and Process Systems Engineering.

2. *Prof. Emily Grant* is a senior lecturer at the Faculty of Science in the Department of Chemistry and Polymer Science at the University of Stellenbosch. She runs a multidisciplinary research group with interests in Medicinal Chemistry, Chemical Education and the Philosophy of Science, Education and Chemistry.

3. *Prof. (em.) Bradley Hunter* served as Head of the Department of Chemical Engineering, Dean of the Faculty of Engineering and the Built Environment as well as Acting Deputy Vice-Chancellor at the University of Cape Town before his retirement in 2009.

4. *Dr. Stephen Jones* of the Faculty of Engineering and the Built Environment at the department of chemical engineering at the University of Cape Town is director of the Centre for Catalysis Research.

5. *Prof. Carol Smith* is also from the Faculty of Engineering and the Built Environment at department of chemical engineering in the University of Cape Town. She teaches chemistry to undergraduate engineering students. She is also a student advisor to first year chemical engineering students.

Table 13: Lecturers' profiles

Interviewees	**Faculty/department**	**University**
From Germany		
Prof. (em.) Dr.-Ing. Jan Bremer	Applied Mechanics	Technische Universität Clausthal
Prof. Dr.-Ing. Andreas Kleid	Production Engineering	Universität Bremen
Prof. Dr.-Ing. Antonio Marco	Production Engineering	Universität Bremen
Prof. Dr. Dr. Jonas Schneider	Physics & Electrical Engineering	Universität Bremen
Prof. Dr.-Ing. Maria Schwartz	Production Engineering	Universität Bremen
From South Africa		
Prof. Chad Block	Engineering & the Built Environment	University of Cape Town
Prof. Emily Grant	Chemistry & Polymer Science	Stellenbosch University
Prof. (em) Bradley Hunter	Engineering & the Built Environment	University of Cape Town
Dr. Stephen Jones	Engineering & the Built Environment	University of Cape Town
Prof. Carol Smith	Engineering & the Built Environment	University of Cape Town
Total: 10 (Note: 7 male, 3 female).		

During the interviews, these lecturers shared their views on issues ranging from the purposes of engineering education to pedagogical practices they employ to encourage critical thinking. They were also asked about the extent to which they felt students understand the complexity and interconnection of trends influenced by technological innovations and how the engineering curricula at their respective universities are addressing sustainable development concerns (see appendix D). The following section presents the corresponding findings.

7.3 The purpose of engineering education

The goals of engineering education are described in various ways, ranging from the purpose of equipping graduates with knowledge and competencies for work, to the purpose of helping students realise their potential in any area of life. Whereas some lecturers describe the purposes of engineering education broadly and speak of outcomes that are related to enhancing students' autonomy, decision-making abilities and self-determinism, others use 'toolbox' analogies to refer to skills students need for employment.

Prof. Schwarz's (GER) explanation of teaching and learning in engineering is that lecturers do not 'teach engineering'. Rather, she purports that lecturers teach students one of many subjects that they can build upon and connect with other subjects to result in the practice known as 'engineering'. She describes this as a practice that continuously changes and is developed throughout one's academic and/or professional career and she asserts that universities are also responsible for developing students' bravery to use engineering knowledge throughout their lifetimes:

> *People who invented laser technology, who built up the laser machines, the first ones [engineers] never learned about lasers during their studies. They learned about physics, about mechanics, control theory…they learned about design. And then someone had an idea and they were able to transform their basic knowledge into a new field. And that is what we are heading for in university; to give the students the ability to deal with the first job and then five years later to deal with the second job, and the third job and then we have to make them fit for the next fifty years of technological improvements. To deal [with], to understand, to develop and to further enhance. So that's what we give them. What I think- what I expect them to take. Yeah? The knowledge, the methodology and also the courage to use it.*

Just like the lecturers interviewed in this study, engineering educators do not teach students *how* 'to engineer'. Rather, they are involved in teaching them a variety of subjects that students need to know in order to be able to perform various engineering functionings.

Prof. Schwartz (GER) describes the goal of engineering education using similes and metaphors, sometimes even extrapolating moral lessons from films to bring her views across. Using a scene from the science-fiction adventure movie, *Indiana Jones and the Temple of Doom*, she describes what engineering students are being prepared for by universities. Referring to the film's main character, she compares Indiana Jones's challenge[35] to traverse unsteady terrain, to challenges engineering graduates will face as professional engineers. In doing so, she indicates that engineers often have to make decisions under difficult and uncertain circumstances and she argues that university education aims to prepare students for similar situations that they are likely to encounter at work (and in life). From her perspective, the purpose of engineering education is to develop students' capacities to make decisions autonomously and develop innovative approaches and methods to solution seeking, which are founded on engineering knowledge:

> *When he (Indiana Jones) is in the temple in Petra , then he has all the tiles [in front of him] and some of them break down and some of them are stable. All of our students have to go, during their career, through such a field and you never know in advance which way is the right one for each of them. And what we're doing in the student time is that we build up these tiles so that we give them the opportunity to build up on them, to build new houses on these tiles, and to be able to decide which tiles to use and to be able to make up new things from the common ground. To build up new things, new ideas, new products, new processes from what they know basically. And we give them both the knowledge and the methodology to deal with the problems.*

Similarly, Prof. Kleid (GER) describes the goals of engineering education broadly. He is disinclined to name specific goals that engineering education has. Instead, he describes the aims of the engineering faculty as being to prepare students for the world of work and for life. He does however emphasise the importance of keeping engineering production 'a German thing', which suggests the pride he has in the quality of German engineers. It also indicates

[35] In the film, Indiana Jones has to tackle a challenge called 'Only in the footsteps of God will he proceed.' This challenge comprised of a series of lettered tiles on the floor. The object was to figure out the secret keyword, and then step on the letters that correspond with the correct spelling of the word. Incorrect tiles would break through, potentially causing the seeker to plunge into a deep chasm below the floor.

that he acknowledges how doing so also supports national development imperatives. He sees this way of identifying with the profession as being an important element to the development of German engineers. He says:

> *We at this faculty do not have specifically formulated goals per se, and this is somethingwhich is continuously being discussed by us. We are called Produktionstechnik*[36] *and I would say the overarching aim of all my colleagues or of the faculty, is to educate young people during their time at the university so that they in the end are capable for employment, capable for the future, on one side. But one goal that is also always present is that we keep production in Germany. And that is the overriding aim. One could break it up into sub sections but it's about educating excellent engineers who uphold this strength even in international comparison; helping to further develop them.*

Prof. Kleid (GER) also argues that, as a result of their higher education experiences, graduates should develop a sense of freedom about whom or what they want to be in the world. His view suggests that he finds it important that engineering education (and education in general) develops students' sense of independence to determine their futures:

> *In my view they should, at the end of their studies, and this is one of the major goals of education- and you won't achieve this for all students because it's also a societal problem- we must manage to give as many students as possible the feeling that they can determine their own position. And we have to strive for that…[that] students see their position. And that, they must know for themselves.*

Prof. Kleid (GER) elaborates this view about the goals of engineering education and his response is powerful because it focuses, not on predetermining what students should be or do once they complete their studies, but rather on the *opportunities* that should be available through university leaning. This view resonates with a capabilities view of development, where development is defined as freedom i.e. freedom to do and be what one has reason to value. He also stresses the outcome of stimulating students' curiosity. This implies that he assumes students enter universities with a desire for knowledge and inquisitive, questioning minds. He argues that university education should stimulate this curiosity and help students

[36] Production engineering

recognise opportunities where they can successfully applying what they learn. That is, to help students imagine new areas where their engineering knowledge can be used:

I believe (...) we have to offer more options where young people can be successful. And we have to show them what they can do, not what is impossible. Rather show: "here, you can do this"... "and that". I think it's much more about awakening curiosity…. I think it's also educators who have to change, right? In the long run university should awaken student's curiosity, and provide an environment where that can also be served, or satisfied. And that is in my view one of the biggest challenges.

As mentioned earlier, not all lecturers' views on the purposes of engineering education were broad and abstract. For example, Prof. Marco (GER) describes these goals as threefold. Firstly, to provide foundational theoretical natural sciences and engineering knowledge, through subjects such as mathematics, physics, chemistry etc. Secondly to teach students the practical application of that knowledge at its more advanced stages, which is achieved through compulsory *Praktika* or internships (locally or abroad). Thirdly, to advance research that is carried out across various departments in the engineering faculty, where students have the opportunity to do a *Forschungspraktikum* or research based internship. To summarise, he sees research-based learning as an umbrella concept for the three main goals of engineering education and sees it as the means through which engineering students are prepared to become qualified engineers:

The concept of 'forschendes Lernen' is quite big here at Universität Bremen: you learn through research. So you have these three aspects: the fundamental sciences, the research and you have the practical applications. And all three contribute then to your qualification.

Some lecturers at the University of Bremen mentioned that breaking up the old Diplom five year programmes into a three plus two year cycle structure is not desirable. These concerns are raised due to the idea that at the end of the three year period, students have completed the foundation phase of their path towards becoming engineers, but are still far from having the capacity to independently perform engineering activities in professional settings. Prof. Kelid (GER) says:

I am not particularly for the bachelor master system. Many German engineers aren't. (...)I am against the idea of someone coming to the university and leaving with a *bachelor degree (...). Even if someone goes somewhere else, we try to advise them to go to another university, don't go straight into work- well if one really wants to then they should- but the advice goes more in the direction that one should study further to get a higher degree.*

Prof. Hunter's (SA) view similarly focuses on what students need to be able to do before they qualify as engineers. However, his terminology is quite different to that of Prof. Marco (GER). At this point it is interesting to note that words such as 'toolkit' 'toolbox' and 'tools' are used almost only by the South African lecturers. The words toolbox and toolkit generally refer to sets of graduate attributes (engineering education outcomes) and the tools would therefore be a particular skill (e.g. the ability to calculate complex mathematical equations). For example, Prof. Hunter (SA) says the goals of engineering education are to:

To provide a student with all the necessary tools so when the student leaves university they've got the tool box to start out becoming an engineer.

Prof. Grant (SA) says similarly:

Engineering education is about giving students the toolkit they need for employment

These responses resemble the kind of language one might associate with utilitarian views on education, where education is primarily defined in instrumental terms according to the competencies (skills) a student can acquire through education, for the sole purpose of employment. Also emphasising the tools that students need for employment, Prof. Jones (SA) gives an example of what university learning ought to prepare students to do. However, his response focuses more on developing students' potential to take responsibility and be accountable for engineering outcomes:

Engineering education should prepare the students for taking over responsibility in a plant environment and responsibility for the people working there and for the products that the company produces for world markets.

Some lecturers also emphasise that what graduates take with them from university is just enough knowledge to *begin* understanding the broader spectrum of the engineering profession, which allows them to gain relevant work to register with professional bodies. Prof. Smith (SA) says the following about engineering education in universities:

I think it's important to say that it's the one stage towards your becoming the engineering professional.

The stages to becoming a professional engineer are described at length by Prof. Hunter (SA) who emphasises that upon graduation students haven't become engineers yet, but are at the stage where they have what it takes to grow into being an engineer:

It takes seven years to produce an engineer, four years at university then they get the thing called a degree which is a starter pack and then three years as a candidate engineer in industry. [They get] registered with ECSA then they are ready to start practicing as an independent engineer. So that is why I feel very strongly when consulting companies come around the engineering faculties and try to recruit our very clever students into becoming consultants the day after they graduate; that's a crime because they haven't become engineers. They've got a tool box. And I'm worried that the modern current thinking on engineering education is failing to remember to give the student a good tool box.

What emerges clearly from the data is that German and South African lecturers talk differently about the purposes of engineering education. When looking across the data, it is easily observable that the German lecturers speak about the goals of engineering education quite broadly. Based on their views, engineering education seeks to:

- Develop students' capacities to make decisions autonomously and create innovative approaches and methods to solution seeking, which are founded on engineering knowledge;
- Enhance students' sense of determination to be and do what they have reason to value in life as well as determine their roles in society;
- Stimulate students' desire for knowledge and help them recognise opportunities where they can successfully apply what they learn, in their work and in their lives; and
- Provide students with opportunities for research-based learning.

These four goals reflect and are consistent with skills like i.e. critical thinking and open-mindedness, which emerged from the data on employers' views. They therefore represent attributes that are seen as desirable and pivotal outcomes of engineering education.

On the other hand, South African lecturers speak more narrowly about the goals of engineering education. Based on their views, engineering education seeks to:

- Provide students with the necessary knowledge and skills that they need to become engineers and be employable; and
- Develop students' potential to take responsibility for running engineering organizations and be accountable for the engineering outcomes produced by them.

Having anticipated that some lecturers' responses might focus specifically on the goals of engineering education in relation to graduate employability, I had a question in the interview schedule that was directed at finding out what lecturers thought about the value of engineering education beyond preparation for employment. In this question, I asked each interviewee to comment on a statement that draws substantially from Boni and Walker's (2013) view that universities ought to advance equalities and contribute to sustainable and democratic societies. The statement read:

> Education institutions should also promote social goods, through enhancing personal development, contributions to society, fair participation in the economy, well-being, participation and empowerment, equity and diversity, sustainability, world citizenship, imaginative understanding and freedom.

South African lecturers' responses to this comment illustrate that their views on the goals of engineering education are not far from those of the German lecturers. On the contrary, they seem to share similar ideas about broader contributions higher education should make to students' development. However, they seem more concerned with the structural, economic, temporal, and institutional constraints that make it difficult for universities to achieve the goals noted above. For example, Prof. Jones (SA) says:

> *I think that is a true statement for the original idea of the university, for what is called in Germany at least the Humboldt ideal of the university. University is the place where people study, as opposed to being taught, right? Where they are so directed in their study that they have mentors that guide them in their study and as a result of the process of studying they come out as complete persons, personalities. All of that really epitomises what you just described. There's a lot of political terminology in that sentence but in essence what it means is the ideal citizen is described by those qualities that you just read to me. And I do subscribe to that ideal. In the actual study*

environment it is met with realities of the sheer mass of students and the limited resources in terms of infrastructure and financing and skilled educators…to actually allow this to happen.

Prof. Jones (SA) continues and expresses concern about the extent and reach of universities to impart values and attributes mentioned previously, also speaking of that challenge within the engineering profession:

> *I don't know whether that challenge is easily addressed at a university programme level, I'm not sure. I think we can do a lot more to sensitise students to the need to take on their personal responsibilities for the things that you mentioned there and it is a challenge for the profession. Sometimes I worry that the (engineering) profession doesn't have the profile that it ought to have in society.*

Prof. Jones' (SA) views clearly shows he has similar ideas about the purposes of engineering education as his German counterparts do, and his opinion is typical of the South African lecturers views. This led me to wonder why South African and German lecturers articulated the goals of engineering education in very different ways, if their views are fundamentally similar.

The most likely reasons why the German and South African lecturers responded so differently include that high levels of unemployment in South Africa often place employability concerns at the forefront of conversations about education outcomes. It is also possible that the lecturers are aware that many students encounter barriers to accessing higher education because of high university tuition fees and the fact that many students come from a low or middle-income households that struggle to pay these fees. Because of the high price tag attached to university degrees, South African lecturers might primarily focus on whether or not the knowledge imparted by universities actually leads to employment, as being employed means a brighter future in terms of having more economic freedom (which is beneficial not only to the individual graduate, but to their family too).

On the other hand, zero university tuition fees in Germany and more favourable economic conditions means that lecturers (and students) are probably more concerned with broader education outcomes, as opposed to being worried about 'getting their money's worth' out of university education. This is reflected in the findings from the focus group discussions with students (discussed in chapters 8 and 9) where South African students similarly raise concerns about their employability when talking about their education, whereas the German students do not. As such, it appears that South African lecturers and students *talk* about the purposes of engineering education differently to German lecturers. However, this does not necessarily mean that they *see* the goals of engineering education differently. Rather, it appears that less favourable socio-economic conditions in South Africa influence the emphasis placed on the issue of employment when talking about higher education outcomes. On the other hand, more stable socio-economic conditions in Germany might make it easier for lecturers and students to focus more of their attention on broader outcomes when talking about higher education.

Although universities ought to enhance engineering graduates' capability for employment by ensuring that students learn appropriate technical skills to be employable, this should not be done at the expense of enhancing students' opportunities to learn how to: make decisions autonomously, determine their roles in society or recognise broader opportunities for intrinsically meaningful employment. In addition, engineering students should have opportunities to learn how to think critically, become more open-minded as well as communicate and collaborate effectively with diverse teams. As argued by Nieusma and Riley (2010) by placing technical functionality at the centre of development work, engineering-for-development projects and engineering activities in general tend to obscure non-technical dimensions of development work that are pivotal to achieving social justice goals (Nieusma & Riley, 2010).

Therefore, an over emphasis on the importance of technical skills for employability in engineering education, is not in the best interest of developing 'whole' engineers or public-good engineers. That is, engineers who not only have a sound base of technical engineering knowledge but are also critical thinkers who can apply this knowledge appropriately in practice whilst being fully conscious of their roles in society and willing to use their agency to promote social justice and advance sustainable human development as a public good.

7.4 Developing an engineering identity

Prof. Schneider (GER) argues that engineering knowledge can go a long way in affecting graduates' occupational identity and commitment to the engineering profession, explaining that this is dependent on developing deep and meaningful understanding of what they are actually doing:

Professional identity (...) is for personal development, extremely important…and in so far the quality of occupations are very important for the personal development and of course for commitment. If a person understands what he is doing, he's not only a robot doing what the boss says.

Correspondingly, Prof. Schwarz (GER) explains the value of engineering knowledge by describing the role of engineers in society and explains what it might mean to identify oneself as an engineer. Using an analogy about different levels of participation in a societal cause, she reasons that engineers' assignment in society is to be proactive agents of positive change:

I say we have different roles in society, there are people who climb on the trees to say save the trees, and that's one role. And the engineer can say what can I invent that I do not need them [trees] anymore for my product? So I wanted to be the one who thinks about the better solution, the best solution instead of just saying I'm against it. Of course it's important that people say I'm against [something] but that's not enough. That's just the beginning. It doesn't help us to be against everything. We've got to be for something. So the question is what is it for? And that's from my point of view the engineering subject. To be for something.

Prof. Schneider's (GER) perspective is that engineers and other professional groups that contribute to the creation and design of development projects fail to make just ethical judgements in this because of their education. In particular, he talks about the failure of universities to impart engineering knowledge that encompasses understanding of the reasons behind the necessity for technology. He calls this the 'purpose-means relationship', defining technology as a 'realisation of human needs':

Every technology is ultimately the articulation of a societal purpose, otherwise it would not exist. Every technology is the materialization of a purpose, backed by interests, which are backed by needs and dreams. Needs and dreams are translated into interest by the people. There is a balancing of interests, then there is a purpose. Out of it engineers create specifications and these specifications become products and processes which are bound by the feasibility allowed by technology and science.

Prof. Schneider (GER) also argues that the problem with technical subject matter is that it is taught as an objective science, rather than as knowledge that has its own set of pre-existing values. He goes on to explain that leaving it up to the state to decide on the appropriateness of technologies for society is problematic because this results in a top-down approach that causes engineers to function as objective technical experts whose knowledge enables them to contribute to innovation, but whose value judgements are not meaningfully considered or required in the process:

> *They [engineers] are taught in the university: technology is value-free. And they have no responsibility for why and they have no responsibility on the follow up, they leave the politicians to think about that; (...) this is wrong. It's basically wrong because every technology is the articulation of a societal purpose, and if you don't understand the purpose and where it comes from then you have no understanding of technology, that is the problem. And engineers normally, especially in universities, have no understanding of technology, they don't understand it. Really they don't understand it. They have knowledge of how it functions. But not why is technology this shape, and its effects-no idea. In so far they are connected to possibilities, but not to the needs and purposes.*

In the excerpt below Prof. Schneider (GER) again shares his thoughts on why he believes engineers have a precarious understanding of technology effects that may lead to them unknowingly contributing to unjust ends. He also states that the biggest problem lies in engineering curricula that are reduced to modules that emphasise the 'how' of technical knowledge and technology at the expense of knowing 'why' certain technologies are more worth creating than others, if the goal is accomplishing sustainable human development. He believes that it is therefore easy to use engineers for unjust ends. He says:

> *If there is a dictator who says do this or do that they [engineers] would do it. Because their implicit education is a problem, they don't understand technology. They only understand how it works, how to produce, how to do research…And they believe it's value-free…unbelievable!*

A helpful way to get engineering students to make inferential sense of propositional and procedural knowledge is suggested by Prof. Hunter (SA) who says giving engineering students examples of the context in which their knowledge might be used in the world of work is a good starting point:

> *A nice pedagogical approach for me is that any lecturer the first lecture or two of a course should be the context. I'm going to teach you reaction kinetics, I'm going to*

teach you-I'm a mechanical engineer I'm gonna teach you fluid flow. I'm an electrical engineering lecturer and I'm going to teach you semi-conductors…so the first thing you must help a student understand: why do I need to know about this if I want to be an electrical engineer? So it's critical for me that the lecturer should put the course into context. Now sometimes curriculum changes are such in nature that we think too much about the psychology and teaching and all that good stuff but it's just simple stuff and that's coming back to my tool box. I'm going to give you a tool box and I want to make sure when you leave UCT or Pretoria university or whatever you're coming from you've got a reasonably good tool box and you roughly know which tools you've got in there and what they are there for.

Asked if he thought students are able to make connections between engineering outcomes and broader issues such as the ideal of social justice, Prof. Block (SA) answers:

I would say generally not; but there will be individual students who have a deeper interest and who do a lot of reading in addition to their studies who might make some sense of these things; but they are not equipped with any tools in particular to then translate that broader interest in innovation and technology and society and responses to global warming or whatever,[and how] to take that broader thinking into their engineering practice.

Likewise, Prof. Hunter (SA) emphasises the importance of understanding the necessity of engineering subjects to help students realise the relevance of certain courses that may otherwise be perceived as irrelevant to them. He argues that students should be able to ask themselves the following kinds of questions and develop answers to them too:

'So why do I need to know fluid flow? I'm gonna be a civil engineer, do I need to know about water? [Yes] because civil engineers design sewage pipes. So that's why I have that tool in my tool box!' Whether you're gonna use that tool later on depends on a lot of things you may never use that tool again because you may go off into some sector in industry and mechanical engineers may go into aeronautical engineering and not use some of [that knowledge]. So I think lecturers need to be thinking about what competences they want their students to have when they finish the course and why. How does it fit in to the discipline?

Prof. Schwartz (GER) explains that her interest in mechanical engineering was based on what she knew about the profession and what she thought of the possible application of that knowledge. She argues that engineering knowledge is more widely applicable than knowledge gained from economics or commerce-based subjects, and she asserts that more people with this kind of knowledge should be in leadership positions of companies as they have more potential to advance positive change in society:

> *So I ended up in mechanical engineering because I thought that is something where we can change things, [where] we can also change things in economics because we understand something in economics much more than economics people understand from technical science. And that's what my experience was, that we need more people also in leadership who understand the details and also the connections. Who see how all the processes are interlinked between humans and things; between different disciplines. Everything is interconnected and that was my personal reason why I was in the subject because I saw that's the subject where I can change things, really change, not talk about-but do, and I think that we can do.*

7.5 Teaching non-technical skills

As discussed in the literature review (chapter 3) engineering education programmes around the world are increasingly undergoing reform to incorporate humanities and 'sustainability' courses in their curricula. These changes reflect examples of efforts in higher education (especially in universities) to balance technical skills with non-technical skills, in order to ensure that future engineers are 'whole' engineers. This section discusses how engineering lecturers perceive the teaching of non-technical skills. First, I discuss their views on how this can be achieved through curriculum reform and thereafter I discuss their views on the kinds of pedagogies that are helpful in enhancing students' non-technical skills. To conclude, the chapter considers the implications of these perspectives on teaching and learning in engineering, from a capabilities lens.

7.5.1 Appropriate curricula

Similar to recommendations provided in the review of literature, most lecturers stressed the role of curriculum in imparting non-technical skills. For example, Prof. Smith (SA) speaks of a reformed chemical programme at University of Cape Town, which is characterised by project-based learning and sustainable development as a concurrent theme throughout the curriculum. The new curriculum, she explains, seeks to engage with sustainable development challenges more explicitly by incorporating 'sustainability' theory and principles into technical courses. Doing so, she argues, results in opportunities for students to think about the results of engineering activities more broadly, which creates opportunities for students to think more critically about what they do as engineers:

> *For critical thinking specifically there I would speak particularly to the new curriculum (...) which has project work throughout and I think particularly having sustainable development now as a strand of what is taught in first year chemical engineering, alongside with -how do you work with chemical equations and calculations- that opens things up quite dramatically*

The notion of embedding or integrating non-technical skills in engineering curricula is popular amongst all lecturers. However, some are hesitant to promote ideas about deep curriculum reform. For example, Prof. Block (SA) explains the difficulty of the balancing act that goes on, in deciding what should change in the curriculum and what should stay as it is. He concludes that adding new courses to already congested curricula is problematic, but acknowledges that desirable skills for engineering practice change over time, and that this necessitates re-evaluating the content of engineering curricula:

> *But yeah how do you reform a curriculum? How deep do you go? (...) You know? People don't want to throw out what was there because that was good; they just want to add add and add and that just can't be you know? So, we only have four years with the students…so how do you reform that curriculum? What matters to a generation that has calculators on phones?... and powerful ones too! So, you know? Do you need to be able to prove theorems if you want to engineer? Or do you need to know how to store your data on a cloud? (...) what are the skills that are needed these days?*

Similarly, Prof. Kleid (GER) is concerned about what might be lost due to making too many changes to a fundamentally good engineering curriculum. He indicates that 'curriculum reform' often manifests in elective courses being added to the curriculum which results in overcrowded study programmes:

> *In the past I also did a lot of study advising, and then I also spent some time on the examination board, and I find it shocking how tightly structured many programmes are (...). And in the past, especially in the engineering sciences, we didn't have things*

like that [elective humanities courses]. I'm not saying that everything in the engineering sciences was good, no that's not what I'm saying at all, there is always something to adjust, especially along with changes in society, but one could have done some things differently without endangering that which actually functioned well.

Similarly, Prof. Smith (SA) acknowledges the complexities and challenges of curriculum reform measures. Although she is a proponent of adjusting engineering curricula so that they might enhance students' non-technical skills, she emphasises that engineering curricula ought to remain dominated by technical subject matter. That is, priority should not be given to having courses that develop students' transversal skills, at the expense of teaching courses that are indispensable to the technical aspects of engineering practice:

Look it's a challenge because you have a programme where also you have to-remember there's a lot of detailed technical work students have to do. You cannot get away from that. They're not going to be the professionals who can tackle these problems if they don't have that technical base as well, so the integration and balance of those elements. I think that's the challenge going forward.

While most lecturers' responses brought attention to issues of curriculum reform, others spoke more about pedagogies they thought might be helpful to enhance students' non-technical skills. As discussed in the review of literature, popular engineering pedagogies that are directed at broadening learning outcomes include project-based learning. The lecturers' responses that centre on engineering pedagogies similarly cite project-based learning as a good method of teaching non-technical skills. As Prof. Schwarz (GER) explains, pedagogies for teaching critical thinking include project work, teamwork, and facilitating open discussions or debates. She explains:

That's one thing I do in my classes. So we have discussions. Even if there are one hundred and fifty students in the class-we have discussions. Open discussions. For me it's important, so I try to do that. One point. Second, I'm teaching design. And we do practical exercises in groups along the whole semester, and the groups have to present four times in the semester. Everyone in the course has to be at least once at the front to present. And they are not presenting to me. They are presenting to the other [students]. So I normally only ask one question maybe just to be a little bit polite. What I force the guys [to do] is to present to the group, and the group is asked to understand and then they start this dialogue. And over the semester you can see *how they learn to think about people-other people's solutions, to ask the right questions, to answer these questions, to reflect on what they are doing-sometimes I jump in just to give a little bit of process help-so I like to ask the question: do you know what's happening here now?*

Replies that dealt with other examples of what can and should be happening pedagogically to impart transversal skills were few but powerful in demonstrating how engineering educators sometimes have to come up with ways to do this, based on intuition rather than on practical and clear guidance from their respective departments or universities. That is, engineering lecturers sometimes experiment with teaching methods that are uncommon in traditional 'chalk and talk' engineering pedagogies. These experiments are based on the assumption that they are effective, fuelled by the lecturers' observation or gut feeling and random student feedback rather than on formal, tried and tested assessment techniques. This is reflected well in the quote below which captures what Prof. Kleid (GER) replied when I asked if he thought the innovative teaching methods he employs were resulting in desired outcomes for his students. He answered:

I go on that assumption, but we haven't done any research on this, but I can only work with the feedback that I get from graduates. Feedback that I have heard often is that when they are in companies and compare themselves with others, they often say we did this or we did that already, they have great project management competences and not just theoretically, so they don't only calculate the risk in the plans of a particular structure, but they have hopefully also fought with their class mates, about upholding appointments and so forth. That is something which is very important, and that one actually does it sometimes, that is also something that engineering in Germany is strongly influenced by-there is always the theory, but there must always be that element where one has understood the theory and then applies it, otherwise theory is just memorising information. And that is an element which is common in all engineering education in Germany.

Prof. Kleid (GER)'s response brings light to the fact that there is inadequate data or literature that deals with appropriate and reliable evaluative measures of the effectiveness of novel engineering pedagogies in teaching transversal skills. Although graduate feedback can be useful in helping to determine this, more systematic and reliable ways of discerning how helpful such measures are in the long run are necessary. This might enable higher education institutions to model pedagogic shifts drawing from real examples of what works well and what does not in teaching transversal skills in engineering education.

7.5.2 Helpful pedagogies

Examples of pedagogies perceived as doing well to impart transversal skills are given by Prof. Schwartz (GER) who is a proponent of project work in teams, claiming that the lessons the students take from this kind of learning range from critical thinking to effective communication and the capacity to collaborate with diverse people:

> *We train them in projects where they can only succeed if they have one solution together. Where they need to arrange with other people, to learn to criticise other people, learn to take criticism, learn to think about solutions from other people. (…) Not just, 'what do I like?'/ 'what do I not like?', but also 'how can you improve?'. And that's something we teach them on the way in the technical aspects, it's not extra soft skills. And then also we have soft skills like presentations or moderating; we teach them, I do-teach them, how to use flip charts, meta plan, how to go through creative technology to get new ideas. We teach them about the process design, not technological but business process design, so we give them along a lot of other knowledge, but one of the basic things is that we bring them forward along the way to be a team player.*

Another example is provided by Prof. Bremer (GER) who tells how he encouraged students to talk about what they do. He is concerned that there are limited opportunities for students to practice articulating their thoughts, ideas, or opinions:

> *(…) we suffer from the problem that, and I am speaking of Germany now, limited opportunities to articulate themselves verbally. I introduced in the example in the course technology assessment-and within the Diplom programme, I always requested that they talk about their work once, twice, three times in a seminar during their course of study. That is way under emphasized-and here we're now in the field of social sciences and humanities, so philosophers, sociologists where there is great emphasis on verbal articulation…the engineers lie far behind.*

Similarly, Prof. Schwarz (GER) often facilitates debates in her classroom. Through this, she tries to teach her students lessons about decision-making and critical thinking processes:

So what I can give the students is: always to be aware that they have to make decisions based on what they know and to try and be thorough about what they do, to be careful, to rethink- but then to decide. And to know that they may be wrong. And the only thing I can teach them is that they are- in the moment they decide-sure that it's the best that they can decide at that moment. We cannot do more.

Correspondingly, Prof. Smith (SA) explains that encouraging students to talk more openly in class, and having open-ended discussions can go a long way in helping students practice critical reflexive thought. The example she provides below, speaks both to appropriate engineering pedagogy to teach transversal skills, and appropriate course content that aims to do the same. She highlights the importance for case studies used in engineering courses to have appropriate, relatable, context specific content that looks at contemporary issues such as sustainability challenges, while combining that with facilitating discussions that help students realise that there are dilemmas in seeking engineering solutions which make it difficult to judge whether one solution is better than the other:

I guess pedagogically…where I have worked in that space and my colleagues as well has been in quite open ended classroom discussions of the sort you wouldn't necessarily expect in engineering and in project tasks which ask I mean like the one project which I was- I had two modules last year: one's a case study of a sewage plant, a waste water treatment plant and the case study has a formal settlement an informal settlement and the waste is run in particular ways [what students have to do is] look at the whole thing and ultimately come up with 'what do you think we should do?' And there's no one way to answer. You know? Should we be focusing on sanitation for informal settlement? Should we be doing this? Should we be doing that?…What's the bigger picture? I think that's quite a broad engineering task and that's done by first years and they do a range of, I mean they do topics on bio-fuels as well so you know there's the question do you use like arable crop land for growing fuel? So, you know, they had to get into all those discussions. So I think the project work drives quite a lot of that. And then I mentioned the safety talks as well so there's quite a lot of that, let me say, sort of thinking critically about the context of engineering

Prof. Block (SA) explains the challenge in teaching such broader lessons and other values that may be conducive to developing 'whole engineers', stating that engineering educators should be role models of the values they try to teach, giving an example of how one might do this he states that:

> *Values are very hard to teach you know you've got to…you've got to model values. You've got to model values I think, I mean you can go into the- and we do in our fourth year course- go into theory behind what are ethics, and why are engineering ethics important and you know the difference between morals and ethics and what kind of constructs can we use to help you think through an ethically difficult situation; but values are some stuff you grew up with. We don't all have the same mother so we have different values and so at the same time you know people come to university in a mouldable way so when I don't rock up in the classroom that often with my cycling helmet but you know my students know I cycle to campus, I don't just teach the stuff.*

With this example Prof. Block (SA) refers to teaching and demonstrating sustainability practices, showing students that contributing to lowering the human carbon footprint on the environment does not necessarily only happen through using engineering knowledge to create environmentally friendly products, but can also happen from individuals choosing their modes of transport more critically. Such decisions are not necessarily based on technical expertise. One can make the decision to use the least pollutant mode of transport available to them, based on general (non-technical) knowledge and disposition towards being environmentally friendly.

It is clear that the lecturers have good intentions and are genuinely interested in finding ways to help their students think in ways that are useful for their personal development. It is also clear that the lecturers are doing what they believe is appropriate or teaching in ways they perceive as conducive to critical thought and other transversal skills. However, because there is little empirical evidence on the effectiveness of the pedagogical shifts mentioned here, it is not possible to judge if these changes do/will have the desired effect. As such it appears that engineering lecturers, who use out of-the-box teaching methods, do so largely based on intuition. However, this is not without value. Lecturers' willingness to attempt different teaching approaches in order to make their students aware of the complexities of engineering is an indicator of the aspirations they have for their students. It is likely that their efforts are fuelled by the hope that their students might become whole engineers and not merely technical experts. Therefore, the value of the intuitive pedagogical shifts applied by some lecturers lies in the fact that they care about and strive towards broadening their students' professional capabilities and functionings.

What all lecturers are convinced about is the value of project work, arguing that it allows students to experience different roles that they may have to fulfil in the world of work, teaches students how to cooperate to achieve joint success, or how they can fail together and develop the resilience to overcome future failure. Prof. Schwartz (GER) explains this well. She says:

> *Something that they learn here during their studies and then something that is very important as a soft skill from my point of view; they learn to fail. They learn to fail, to stand up, get a little angry and then to speed up- and go again and succeed. And I think for the rest of their lives that is very helpful.*

7.6 Engineering lecturers' valued functionings

Based on the findings from the lecturer interviews, it is clear that there are specific doings and beings that they value and seek to achieve in their capacities as engineering educators. Considering the findings discussed in all the sections of this chapter (see summary in table 14), the valued functionings of engineering lecturers can be summarised as follows:

- Helping students to fully recognise the instrumental and intrinsic value of engineering education, and hence achieve its goals (see section 7.3);
- Facilitating students' development of appropriate engineering identities;
- Teaching curricula that are aligned with public-good engineering;
- Using pedagogies that enhance students' transversal skills; and,
- Contributing to the holistic development of students as professional engineers, and as members of society.

7.7 Summative discussion

According to De La Harpe and Thomas (2009), in order for graduates to develop the skills in critical enquiry and systemic thinking needed to explore the complexity and implications of 'development', a deep cultural shift that promotes thinking differently about the ends of engineering education is needed. This cultural shift also requires critical reflection about what engineering students know, and how that influences how they do their work, i.e. for what purpose, by which means and for what reasons they apply engineering knowledge in their

Table 14: Summary of findings from lecturer interviews

The purposes of engineering education are to:	— Develop students' capacities to make decisions autonomously and create innovative approaches and methods to solution seeking, which are founded on engineering knowledge — Enhance students' sense of determination to be and do what they have reason to value in life as well as determine their roles in society — Stimulate students' desire for knowledge and help them recognise opportunities where they can successfully apply what they learn, in their work and in their lives — Provide students with opportunities for research-based learning — Provide students with the necessary knowledge and skills that they need to become engineers and be employable — Develop students' potential to take responsibility for running engineering organizations and be accountable for the engineering outcomes produced by them
Developing an engineering identity entails:	— Recognising that technology is ultimately the articulation of a societal purpose and that it is *not* value-free — Developing a deep, meaningful and broad understanding of what engineers do — Seeing engineering as a means of serving the public good to achieve positive change in society
Teaching non-technical skills requires:	— Curricula that are aligned with public-good professionalism — Unconventional engineering pedagogies

professional functionings. This speaks to Muller's (2013) argument that students, particularly in STEM fields, need to know how to make appropriate inferences and inferential relations between propositional and procedural knowledge, before going into the field of work.

Drawing from the work of Winch (2013), Muller (2015) argues that every area to be educationally mastered in the curriculum can be described in terms of: 'know that', or propositional knowledge and ‘know how’, or procedural knowledge (see Winch, 2013, 2014). More specifically, Muller (2015) refers to three different kinds of procedural knowledge. The first kind is inferential know how i.e. knowing how conceptual knowledge (the ‘know that’) learnt in the regular courses of e.g. Chemistry and Chemical Engineering hangs together, and how to negotiate the epistemic joints that link the various knowledge ‘bits’ to each other (Muller, 2015). Already between the subjects of Chemistry and Chemical Engineering, the internal conceptual logic differs because of their different epistemic objectives (Muller, 2015).

The second kind is procedural know how. It points to a “more risky and uncertain kind of knowledge” (Muller, 2015: 414) where for example, a novice engineer learns how to find out new things, discover various constraints, figures out what works under certain circumstances and forms new judgments that lead to effective solutions (Muller, 2015).

The third kind is personal know how i.e. the idiosyncratic knowledge accumulated through diverse experiences in the process of ‘doing’ (Muller, 2015). The humanities-based and the technical parts of engineering curricula are epistemically different i.e. they require different kinds of stipulation, they entail different recognition and realisation rules, they have different evaluation criteria and they entail different pedagogic relations (see Kotta, 2011). Referring to different kinds of procedural knowledge as ‘skills’ does not help us describe what they are, or understand what goes wrong when students do not ‘get’ them, or cannot ‘do’ them (Muller, 2015).

Muller (2015) also emphasises that procedural knowledge is sequential. This means that students first have to have reasonable mastery of the ‘know that’ (the conceptual content such as thermodynamics, computer aided design etc.) to begin to grasp ways in which the know how (the practical application e.g. designing sewage pipelines) works. As a result of taking a sustainable development course, engineering graduates may *know that* the results of engineering activities have led to the creation of products such as motor vehicles that contribute to environmental pollution, and they may become aware of various measures currently being taken to fuel motor vehicles from renewable energy sources to lower their carbon footprint. However, this does not mean that graduates correspondingly *know how* to design or create environmentally friendly products. Neither may they *know why* development efforts have resulted in unsustainable ways of living that potentially perpetuate inequalities or social injustice.

Recognising these complexities and being sensitive to the interconnectivity of different forms of engineering knowledge is a capacity that all engineering educators should possess if they are to assist in developing public-good engineers. As mentioned before, engineering educators teach engineering students various natural sciences subjects that equip students with the 'know how' and 'know that' or the tools necessary to be able to practice engineering. However, the data indicates that there ought to be more attention on the 'know why' in engineering education. Know why could refer to knowledge that is concerned with the values, reasons and motives behind professional engineering functionings and technology. For example: Is engineering for sustainable development? Is it for human development? Is technology for social justice? Is it for poverty eradication? Is it for profit?

'Know why' could therefore also refer to the knowledge needed to form appropriate engineering identities, as it relates to the way one sees the purpose of engineering and technology in society, and therefore how one sees the overall purpose of their job. Through the lens of the capability approach, engineering ought to be for all the goals noted above, if these are goals, engineers have reason to value. Therefore, universities should provide opportunities for lecturers to develop, demonstrate, and deepen their commitment to the goals noted above, and to be able to prioritise these goals appropriately in their teaching. Doing so could improve the chances of future engineers being educated by lecturers who seek to enhance their students' capabilities to function as pro-poor, public-good engineers. Engineers who have a combination of appropriate technical skills to perform engineering functions, and appropriate values underlying their conceptions of engineering work, that they might advance social justice through their professional functionings.

This chapter has reflected that the views of lecturers on the purposes of engineering education compliment and are consistent with employer's views on the ideal engineer. However, as noted in section 7.3, German and South African lecturers have more differentiated ways of talking about the purposes of engineering education. On the contrary, such a difference was not notable amongst the employers.

Chapter 8

Students' aspirations, valued capabilities, and functionings

8.1 Introduction

This chapter explores engineering students' aspirations, valued capabilities, and functionings. In doing so, it reveals the motivation behind students' decisions to pursue careers in engineering and explores students' views on their perceived roles in society as future engineers. The perspectives from a total of 18 students enrolled in engineering programmes at masters level underlie the findings reported in this chapter. Four focus group discussions were held between March and August 2014: two at Universität Bremen (German) and two at the University of Cape Town (South Africa). From the sample of students at the South African university, 10 were focus group participants, with each focus group comprising of four and six students respectively. One student was unable to attend the focus group discussions held during my visits to the campus, and we therefore had a one-on-one interview using the same interview guide employed in the focus groups (see appendix F). The remaining seven students were from the German university, with three students in the first focus group discussion and four in the second. There was an equal distribution in terms of gender, with nine male and nine female students (but an unequal representation in the two countries: two female students from Germany; seven from South Africa).

Similar to the format of chapters 4 and 5, this chapter also draws substantially on the voices of the focus group participants. This means throughout the chapter, summaries of my interpretation of the data are broken up with excerpts of students' responses. Beginning with introducing the students, the chapter subsequently describes students' motivations for pursuing engineering studies. This is followed by a discussion on students' aspirations. Thereafter the chapter looks at how the students evaluate their decisions to study engineering. The chapter then explores students' perceptions of their roles in society, which is followed by a discussion on students' valued functionings. To conclude, the chapter reflects on the implications of the findings for public-good enigneering.

8.2 Introducing the students

At the time data was collected, the students from the University of Cape Town were enrolled in their first or second year of a masters programme in Chemical Engineering. Of the 11 participants, seven were Zimbabwean and only four were South African (see table 15 for summary of students' profiles).

Table 15: Students' profiles

Student	Study programme	University	Nationality
Focus group 1			
Anna	MSc. Industrial Engineering	Universität Bremen	German
Lisa	MSc. Industrial Engineering	Universität Bremen	German
Phillip	MSc. Production Engineering	Universität Bremen	German
Focus group 2			
Arnold	MSc. Process Engineering	Universität Bremen	German
Kurt	MSc. Process Engineering	Universität Bremen	German
Markus	MSc. Process Engineering	Universität Bremen	German
Rupert	MSc. Process Engineering	Universität Bremen	German
Focus group 3			
Damon	MSc. Chemical Engineering	University of Cape Town	Zimbabwean
Jennifer	MSc. Chemical Engineering	University of Cape Town	Zimbabwean
Sandra	MSc. Chemical Engineering	University of Cape Town	Zimbabwean
Wendy	MSc. Chemical Engineering	University of Cape Town	Zimbabwean
Focus group 4			
Christina	MSc. Chemical Engineering	University of Cape Town	Zimbabwean
Justin	MSc. Chemical Engineering	University of Cape Town	South African
Molly	MSc. Chemical Engineering	University of Cape Town	South African
Penelope	MSc. Chemical Engineering	University of Cape Town	Zimbabwean
Peter	MSc. Chemical Engineering	University of Cape Town	South African
Valerie	MSc. Chemical Engineering	University of Cape Town	South African
Interview 1			
Trevor	MSc. Chemical Engineering	University of Cape Town	Zimbabwean
Total: 18 students, 4 focus groups			

The students from Universität Bremen were enrolled in their first or second year of either a Industrial-, Production-, or Process Engineering masters degree; all are German nationals. For orientation purposes, all the excerpts from students' responses are denoted 'ZIM', for

Zimbabwe, 'SA' for South Africa and 'GER' for Germany. Although the students from the University of Cape Town have different nationalities, both Zimbabwean and South African views offer global South perspectives and all the students' undergraduate and post-graduate engineering studies took place at the same university.

8.3 Students' aspirations and motivations for studying engineering

It is not surprising that all students cited the aspiration to be employed. When I asked them questions about the future or where they would like to see themselves and how they imagine their lives, most of them gave responses that primarily focused on the kinds of jobs they would like to have. What is interesting are the diverse factors which influenced different groups of students to select engineering as a preferred career. In this section of the chapter, I discuss these factors in order to highlight the conversion factors that shape students' aspirations as well as their motivations for studying engineering. Thereafter I consider what these motivations and aspirations might mean for public-good engineering.

8.3.1 Motivations for studying engineering

Trevor (ZIM) explains how his decision to study engineering was made difficult due to pressure from his parents who preferred that he study medicine. He insisted on his choice to study engineering despite the disappointment shown by his parents. This response shows that his decision was well thought through, and that he was challenged to exercise his agency by being persistent about pursuing a career he values:

> *[when] you are coming from a family where you have parents who have been paying school fees for you, when it comes to that plan whereby you're telling them that 'I'm going to study engineering' [and] there's this thing like 'I want my son to be a doctor' You know? But it's not who you are…It's always a problem for them to understand (…)They would always feel that you made the wrong choice, but as an individual you'll see this is me. This is what I want. This is what I identify myself with. They [parents] will get to a point to understand that it's your decision. Because a career is about enjoying it, not just the money. But anyway I think (…) I'm comfortable, I'm happy with the career I chose.*

Similarly, Jennifer (ZIM) explains that her parents also wanted her to study medicine. Unlike Trevor (ZIM) she was willing to fulfil her parents' wishes but the possibility to study medicine was not an option for her due to institutional constraints that are associated with her legal status i.e. being a foreign student and hence not allowed to enrol for medicine. Her response also shows that she 'genders' engineering disciplines and that she has specific ideas about what constitutes engineering which is suitable for men and women:

> *Growing up, you know how it is when parents instil a career in you? I'd always wanted to be a doctor because my parents had said so. And then when I moved to South Africa the only thing I could apply for at UCT was engineering because they don't take international students for medicine. So of the engineering programmes that were available, chemical [engineering] sounded more "feminine" kind of.*

And while there was interest expressed in selecting a study programme that was challenging it appears that some students had a distorted understanding of the profession based on the information available to them. Again studying medicine is mentioned as a preferred option by Christina (ZIM). She says:

> *I got the wrong impression what chemical engineering was. I initially wanted to be in medicine, which you find a lot of chemical engineers wanted to do, and you kind of just picked up what the next hardest thing was based on you being good at chemistry. And then you come here and realise it (chemical engineering) has almost nothing to do with chemistry and then you're in the system and you try to learn about it. So that was my motivation for being in engineering.*

Unlike Christina (ZIM), Trevor (ZIM) seems to have had a broader understanding of engineering programmes and the capabilities for employment that would be available to him if he studied engineering. He mentions his talent for subjects in the natural sciences, which he cites as factors that made it easy for him to choose engineering:

> *I (…) understand the benefits of studying engineering. Engineering covers everything; [different] sectors. If you want to go into the financial sector you can do that. So it was more of the diversity that the engineering discipline comes with which could also enhance the probability of getting a job; yes. So that's another point and especially in engineering as a person who was more gifted in the sciences, it was also easy for me to be in engineering.*

A noteworthy difference in the students' motivations to study engineering is easily observable. Consider the following responses from German students about the reasons they chose to study engineering. Phillip (GER) notes:

I wanted to study mathematics first because I was very good at it in high school and then I realised in the first semester that mathematics wasn't for me after all because it was too theoretical and parallel to my mathematics course I was already attending mechanics lectures that were offered by Faculty 4. So that's where I realised that was the right thing for me and so I moved to Mechanical Engineering and I already found technology fascinating from early on- I grew up on a farm around tractors and stuff like that so I found it cool and quite interesting to see how things are operated and so when this option was open to me-yeah, so that's why [I decided to study engineering].

Lisa's (GER) statement is quite similar and it is clear that she has a long standing interest in mechanics and technology:

I chose engineering in particular because I've been interested in technology since I was a child (...) and started pretty early with helping my dad repair engines and stuff.

Rupert (GER) explains that his good performance in mathematics and science in high school signalled he might do well to continue with a degree that is founded on natural sciences. Interestingly, he also indicates that he pursued engineering studies in particular, rather than choosing e.g. a degree in Physics, because he perceived physics students as 'nerdy':

I was always I think a little better in mathematics and science classes in school so yeah I wanted to study something that had to do with science and mathematics and this stuff and yeah I didn't want to study physics because I saw these guys sitting there and they were so like…nerds…just my perspective, and yeah I went to study engineering.

So, while most German students' responses indicated intrinsic motivation to study engineering, the Zimbabwean and South African students were motivated to study engineering by dynamics that are more complex. German students seem to have made their decisions to study engineering based on interest in the natural sciences as the main motivating factor. In addition, even when a compromise was made to change or opt for an alternative course of study, the students' personal interest seems to remain the top priority in making a study/career decisions. Anna's (GER) description of her thought process in deciding to study industrial engineering reveals fear of failure in perusing a traditional engineering programme. She describes how she negotiated between her initial or preferred course of study and the course she felt confident enough to succeed in:

I actually wanted to study business management first but that was monotonous for me so I thought I'd rather combine that, with my existing interest in technology and I didn't want to study straight mechanical engineering because I thought it might be too mathematics oriented and that maybe I wouldn't cope with that.

Anna (GER) is the only student who mentions concern of not being able to 'cope' with traditional engineering studies. All other students seemed to appreciate the challenging engineering programmes rather than being intimidated by them. Not surprisingly, some students mention the prospects of a good salary as motivations for becoming engineers. It is noteworthy that only South African and Zimbabwean students provided this type of response when asked to talk about the reasons behind their decision to study engineering. This reinforces the idea proposed in the previous chapter (see section 7.3) that South African lecturers and students tend to focus on the monetary aspects and/or benefits of education ahead of any of its other values. The fact that Zimbabwean students have similar views could be attributed to the fact that prevailing socio-economic conditions in Zimbabwe (and other developing countries in Africa) are even more unfavourable than in South Africa, therefore prompting Zimbabwean students to think first and foremost about their financial futures when considering prospective careers.

Damon (ZIM) is candid about the reasons for his choice of study, explaining that his decision boiled down to competitiveness amongst friends to earn a top salary or get a job that was highly esteemed:

For me I think it was more of the money because like looking at what engineers do and what they get [paid] out of it; it was sort of-it created sort of a motivation. Also considering where I grew up, like there was always a competition from my friends saying like: 'who's going to get the best job ever?', so being an engineer was sought of something high up there. So it was a motivation to get there. That was one of the driving forces to get into engineering.

Justin (SA) similarly considers the prospect of earning a good salary as a motivator for studying engineering. His words indicate that he shortlisted engineering as a study option, mainly based on the prospect of earning a good salary:

I just googled 'top starting salary.'

Of the remaining three South African students, Molly and Peter cited bursary offers, and Valerie cited the advice of her high school teacher:

> *I just listened to my high school teacher.*

It therefore appears the most important factor for South African students' decisions to study engineering had more to do with their perceived opportunity for employment, rather than intrinsic motivation to become engineers. On the contrary, most Zimbabwean students' responses indicate that they would rather have liked to be medical doctors. In summary, the factors which emerged from the data as most influential on students' decisions to study engineering are: lack of opportunity to study medicine (for Zimbabwean students), affinity towards natural sciences or interest in science and technology (for German students), and earning a good salary (for South African students).

8.3.2 Career aspirations

Some students found it difficult to articulate their aspirations. A particularly interesting example of this is provided in Christina's (ZIM) response to what her aspirations are. She explains that she has had to alter her ambitions due to various constraints that made it near impossible for her to do or be what she has reason to value. She therefore feels that she is not in a position to say what she would like to do because of the uncertainty surrounding the feasible options available to her. What Christina says below, is a comment she made after Molly (SA) said she will look for a job upon completion of her masters degree:

> *Can we get those jobs? That's the question. I mean a lot of us, or well I know I'm here because I couldn't find a job. It wasn't a choice to do masters, and even now with a little bit more, like a masters degree and that backing you, you still can't find a job. So you can't even, you may have had a five year ten year plan but if you can't get to some form of market it's… I don't know…I don't know where I'm gonna be in five years.*

To get a sense of what Christina's aspirations were before she realised some of the constraints that prohibit her from achieving her vision, I asked her what she would have liked to be if these constraints were non-existent. Although completely hypothetical in its nature, this question helped her to articulate what she wants, by allowing her to imagine the best-case scenario, and not consider the real barriers to her aspirations. Her response suggests she simply would like to get a job, and later start her own business. She says:

[I] just [want] to get a bit of [work] experience and then after that, assess businesses, and start my own. So maybe five years from now, in that starting phase of thinking of starting my business. [That] is where I would like to be.

Christina is not the only student who considers starting up their own business. Penelope (ZIM) expresses the same wish, but hers is unique compared to all other students as she is the only student who wants to add a commerce-based masters degree to her qualifications. Her response also indicates that she has a keen interest in and appreciation of entrepreneurship:

I'm hoping to go into business after this but I do first want to do two years in the petrochemical industry hopefully, and after that I want to do an MBA in finance.

A typical example of the type of responses that came from the German students regarding their aspirations is provided below. Arnold (GER) who would like to apply his engineering knowledge in research that advances options for energy efficiency, answered in the following way:

I think I will stick to research, not necessarily at the university but some research. And right now I would say I would like to do research about efficiency and sustainability and something like that.

Similarly, Markus (GER) explains that he would also like to do work which is related to sustainable development. His response shows that he has thought critically about ways in which engineers can contribute to sustainable development across various industries:

I think that I will go into industry but it doesn't mean that I have to go into some green peace company to work on the efficiency of processes because if you go to car manufacturer you can still increase the efficiency of the engine or something and you still do something for sustainability and the environment even though you're not working for a green company, so I think it doesn't really matter,…it's not that easy to say you work for a green company or another one, it's more complicated, (by) which fields you are working (in) and what you try to improve. I think that's the main thing engineers want to do they always want to improve something. And if you can combine *the improvement of things with sustainability or energy savings then it doesn't matter where you- or which kind of company (you work in).*

While some students seemed sure of the career path they would like to follow, others were less decisive. Rupert (GER) says he has not yet decided whether he will pursue an academic or corporate career and it is interesting to note that response implies that his employment is solely dependent on his decision to be employed:

I haven't decided if I want to stay and do some research at university, or go into industry but I think a lot of engineering is lot about optimisation as he just said, so yeah always about optimisation of price and yeah, ecological things, yeah so I think I would like to work on optimisation in some way and always keep that sustainability thinking in mind.

Similarly, Kurt (GER) says:

Yeah, I want to work in industry but I don't know exactly, haven't decided.

On the contrary, Wendy (ZIM) has quite clear ideas about what she aspires to be. She would like to pursue a corporate career and she hopes to work in engineering design. Her response indicates that she is aware that what she aspires to might be characterised by stressful work situations. Nevertheless, she weighs this possibility against the odds of achieving happiness or fulfilling the desire to travel and her statement suggests she would consider this a fair trade off for a demanding job:

What I would really like to do is to be a practising engineer, but on the design side, like to be a consultant and I'd like to work on like different projects, even with hectic deadlines…I know it could be stressful but at the end of the day it would be like something that you can look back at and be happy about. And yeah I want to travel overseas.

Similarly, Jennifer (ZIM) would like to work in industry as opposed to working in academia, and she has a specific picture of herself in mind. Below she explains that she finds engineering tasks that necessitate her presence at a plant or construction site quite undesirable. Instead, she would like to work as a consultant:

> *I find it so difficult to picture myself at a plant. Like having that life of always wearing P.P.E.* [personal protection equipment] *every day, I just don't think I'd be happy in that situation.(...) I see myself more in the consulting side, either engineering consulting or some other consulting but then something that I can work [at] from the office and still apply the skills that I've acquired during my long six years at varsity.*

For Jennifer (ZIM) the idea of studying for six long years in order to end up in overalls and a helmet is not an attractive thought. On the contrary, Damon (ZIM) describes this as exactly what he would like to do:

> *I see myself as (...) like- heading like the process engineering [department] in mining and stuff…wearing the P.P.E. and stuff…I think that's basically where I see myself…sometime soon.*

To summarise, the engineering students aspire towards different career paths. While some students would like to continue with conducting research within universities, others are keen to begin their corporate careers in the engineering sector or would eventually like to become engineering consultants. Also, while some have decided that they would like to work in companies that are explicitly pro-sustainable development, others feel that they can do positive work in companies that are not primarily geared towards sustainable engineering, a few students are undecided about where they would like to work and one see themselves venturing into entrepreneurship. There are interesting differences in the way the students spoke about their employment. Firstly, it seems that the Zimbabwean students are primarily concerned about their employability in the first place, whereas the South African and German students seem less worried about the possibility that they might not be employed once they have completed their studies.

In addition, most Zimbabwean students appear to have continued their post-graduate studies out of failure to find employment after their undergraduate studies. When looking at the students' motivations for studying engineering there are also some clear differences. Most Zimbabwean students were primarily uninterested in engineering but pursued engineering studies as a second option to studying medicine. According to the students, they could not study medicine, not because they did not qualify to do so but because international students are not allowed to enrol in medical degrees at the University of Cape Town.

Through the lens of the capability approach (Sen, 1999) and human development paradigm (ul Haq, 1995), if we are to consider education as a means of development or achieving well-being, we need to ask how each and every student is enabled to flourish in and through education (Walker, 2003). This means, if the curricula, pedagogies and institutional arrangements that characterise higher education do not result in graduates' opportunities to be and do what they have reason to value, education cannot be considered as being for human development. Taking a close look at how the students who participated in this study are enabled to flourish, shows different interplays of local and international students' aspirations, capabilities and conversion factors, which ultimately shape their functionings. As the summary in table 8 shows, all (local and foreign) students in this study have the same educational functioning i.e. they are all studying engineering. However, they had dissimilar educational aspirations, and the educational capabilities and conversion factors that influenced their decisions to become engineers vary.

Table 16: Interplay of students' aspirations, capabilities, and functionings

Aspiration to study:	Capabilities:	Conversion Factors:	Functioning; studying:
	Zimbabwean students		
Medicine	Opportunity to enrol in some programmes the student qualifies for	Prohibition to study medicine	**Engineering**
	South African students		
Something that guarantees a good salary	Opportunity to enrol in any programmes the student qualifies for	Ability to enrol in preferred degree	**Engineering**
	German students		
Something that one is good at/ passionate about	Opportunity to enrol in any programmes the student qualifies for	Ability to enrol in preferred degree	**Engineering**

From the table above it is clear to see that while all the students who participated in this study are studying to become engineers, not all of them *wanted* to be engineers. This means that there are students who are fundamentally uninterested in becoming engineers but are opting to do so (right up to masters level) because of limited options to become what they have reason to value. One has to consider the implications of becoming an engineer when students only have extrinsic reasons to do so. Arguably, students who become engineers but do not develop appropriate engineering identities may not care to direct their efforts to public-good engineering. That is, if engineering is only looked at as a mere technical job and a means to a good income, it will not be carried out with the compassion required for public-good engineering. That is, engineering that is pro-poor and geared towards sustainable human development. In the section that follows, I discuss what the students value most about studying engineering. The discussion shows that all the students speak positively about their educational experiences and that even those who were not initially keen to study engineering have nonetheless developed significant appreciation for the engineering profession.

8.4 Valued capabilities and functionings

The range of capabilities and functionings discussed in this section reflect what the students described as things they appreciate most about their studies; such functionings may not necessarily be directly oriented to the public good. While some students spoke about their appreciation of engineering knowledge, and how it broadens their understanding of other aspects in life, others spoke about feeling resilient and feeling like their ability to cope with general life challenges has improved. For example, Kurt (GER) appreciates enhancing his understanding of the technical composition and functionality of artefacts used in daily life:

> *I think I really appreciate it when I understand things I didn't know before, just like things you see every day but you can't really say how it works and you get to learn about them and understand them, yeah I think that's one of the parts that I enjoy just like yeah, getting to know how it works.*

Knowing how things work is closely related to opportunities for using that understanding to solve various problems. The students often said that they feel they can solve any problem and generally attribute this not only to engineering knowledge, but also to the resilience they have developed during the course of their studies. For instance, Sandra (ZIM) explains that she is no longer intimidated or afraid when she is presented with a problem but is instead confident in her ability to solve problems and attributes this to the problem solving approaches that she has learned from her studies:

> *The way I tackle problems I think it's something I didn't have when I was starting my degree, but then now it's like I have it. And I'm not as, like, scared of, like, technical jargon or whatever you know? Even if I don't understand I can still approach and try to understand. So I think maybe the confidence and the way I solve problems [is what I appreciate the most].*

Similarly, Sandra (ZIM) says her analytical skills have improved, and that the way she approached problems when she started her undergraduate studies is very different from the way she views problems now that she is a masters student. She also speaks of her personal development and elaborates on this aspect of her experience at university when she explains that by the time one gets to the end of the fourth year of study failure would be a familiar experience. Asked to give examples of what failure she was talking about, her focus group members gave examples of failing tests or exams that they then had to re-write. The end of Sandra's (ZIM) response triggered her focus group members to talk about overcoming hurdles and learning to keep going after failure. Similar notions are reflected in some lecturers' responses (for example, see page 171). As Sandra (ZIM) asserts:

> *When I see a problem now I feel like, challenged to find a solution, I want to get to the bottom of almost everything…I think that's what I've gained from my past four years. And also I've realised that if you fail at anything you can still get up.*

Similarly, Jennifer (ZIM) talks about overcoming life's challenges and asserts that persistence and hard work result in positive outcomes.

> *The most valuable thing I've gained from-okay first from the four years right? is that life can be challenging, but then if you work hard you can still overcome all the hurdles and as long as you work consistently, things will work out.*

Wendy's (ZIM) explanation suggests that being aware of the failure of others creates a sense of affiliation amongst the students, and that a valuable outcome from this failure is the development of resilience:

By the time you get to your final year [you] start understanding that failure is not, like, something that's 'out there' like, it's part of life. And the most important thing is how you recover from that and move on. Because, now once you've fallen down and you've risen- you're not going to make the same mistake.

Going through the process of failing challenging modules and completing the same module a second time with a favourable grade appears to be one of the factors that instil a sense of confidence in the students' perceived abilities to solve problems, including 'non-engineering' problems. It is clear that the development of resilience and confidence contributes to students' general sense of empowerment and 'can do' mentality. Damon's (ZIM) words indicate this well:

I feel like I can attempt almost anything, even things that are outside engineering. I feel like my mind is more open and I actually enjoy like looking at other problems as well. Like non-engineering (...) problems.

The feeling that one 'can do anything' is linked to the dissipation of fear, which can be attributed to successfully completing a challenging university qualification such as an engineering degree. Sandra's (ZIM) response illustrates this well and shows that her higher education experience has challenged her to cope with different fears that she particularly associated with engineering studies:

I think it takes away your fear as well. Like, I think getting through undergrad you go through a lot to get through it and you just…the fear of hard subjects has gone away… my fear of trying new things has gone away…my fear of fiddling with things has gone away, like in a lab or wherever.

The difficulties experienced during their studies can be described as one of the factors that made the students appreciate the completion of their undergraduate degrees even more. Students also spoke of how they felt their 'smartness' was validated by remarks from people who are impressed that they not only completed an engineering degree but are now enrolled in a masters programme. Jennifer (ZIM) says:

People [think] you're like this super smart person like 'oh you're even doing masters in engineering!'

Comments such as the one noted above, which students said they sometimes receive from strangers, and the positive reaction of family members on graduation day, are some of the examples provided of situations that reinforced the feeling that the challenges and failures experienced in their studies have been worthwhile. Damon's (ZIM) words reflect this well, and they also indicate that he values making his parents proud:

> *(...) in the end it makes you appreciate your degree more when you look at that paper you're like "wow!"(...) And even at graduation you see that they [his parents] are happy, you know? Like, they have brought up an engineer!*

Students also reflected on the breadth of engineering application in industry, citing sectors such as food, mining, transportation, and energy as potential areas of employment. Their responses clearly indicate that they appreciate the opportunity to find employment in diverse fields of work. Christina (ZIM) says knowing this gives her the reassurance that she will ultimately find a job because the set of skills that she has acquired from her degree opens up many options that will become available to her upon completion of her studies. She believes that a masters degree in chemical engineering:

> *[G]ives us the skill set to be able to do anything. Particularly in engineering you can go out into the bank you can go into consultancy, we learn how to problem solve it's not specific to engineering (...) the skill set we get after that is quite diverse.*

Christina's (ZIM) statement contradicts the view of employers who think that engineering students do not have a wide understanding of the work areas where engineering knowledge can be applied. Her words clearly show that she is aware that the knowledge and skills gained from an engineering degree are not limited in their application to the engineering industry. Some students spoke about the lessons and values they now have as a result of their higher education experiences more broadly. As opposed to highlighting how their employment opportunities have been enhanced by studying engineering, some students' responses indicate that they appreciate the opportunity for personal development more. As Anna (GER) explains, studying at a university:

> (…) *also has an effect on the personal side, but I think that is generally the case when you study; not limited to studying engineering but in general. When you study, you grow.*

Similarly, Phillip (GER) talks about the value of university learning quite broadly, citing being independent, taking responsibility for one's well-being and personal development as valuable outcomes. His words also show that, in reflecting about his higher education experience, he considers what happens outside of the classroom as a space of learning and growth too:

> *I think one also learns to be independent (...) you have your own place where you have to take care of the household and things like that. You also learn to be responsible for yourself and it helps in your personal development.(...) I would definitely say that it doesn't only lead to progress in one's career.*

To summarise, students value a range of beings and doings which are enabled by their higher education experiences and engineering education more specifically. Broadly, speaking students appreciate opportunities for growth and personal development through learning how to be responsible for themselves, be more confident, and be resilient and fearless. Students' responses also indicate that experiencing failure contributed to the development of their resilience because it forced them to deal with disappointment in their abilities to pass each exam at the first attempt. At the same time, failure was described as one the worst feelings one can experience as a student. However, feelings of disappointment fuelled by failure dissipated as soon as the students communicated with fellow students and realised that failure was not a condition unique to themselves, but rather a common phenomenon amongst engineering undergraduate students and common in the life experiences of people in general. Being aware of the fact that failure is a common experience creates a sense of normality and affiliation amongst students.

In relation to engineering knowledge, students appreciate deepening their understanding about the technical functionality of how things work, and enhancing their problem solving approaches and techniques. Therefore, based on the interpretation of the findings presented in this section, the students' valued educational capabilities can be summarised as follows:

- Learning how things work
- Learning how to solve problems
- Opportunities to work in diverse fields
- Opportunities for personal development
- Being resilient
- Being confident and feeling empowered

- Being perceived as ‘smart’
- Having a sense of affiliation

Because these capabilities have to be considered in relation to their relevance for public-good engineering, it was important to distil this list accordingly. Having considered the dimensions of public-good engineering outlined in chapter 6, and the goals of engineering education defined in chapter 7, it became clear that the capabilities that are most important for engineers to function as agents of sustainable human development are:

- Solving problems;
- Being confident and feeling empowered;
- Being resilient and having a sense of affiliation; and,
- Working in diverse fields.

From the above capabilities, the following corresponding functionings were extrapolated:

- Applying engineering knowledge to help solve problems and challenges associated with sustainable human development;
- Developing one’s sense of confidence and exercising individual and collective agency to advance social justice;
- Developing a sense of belonging with fellow engineers, and learning to persevere in the face of individual failure; and
- Being employable and having opportunities to apply professional engineering expertise in a wide range of contexts, industries, and job positions for the sake of the public good.

Each capability and its corresponding functioning can be read as ‘if-then’ statements that represent a series of hypotheses about the kinds of beings and doings that can and ought to be achieved through engineering education that is for sustainable human development.

For example, looking at the first capability on the list i.e. solving problems, the following statement would apply:

> **If** engineering education provides students with opportunities to learn how to solve problems, **then** engineering graduates should be able to apply engineering knowledge to help solve problems and challenges associated with sustainable human development.

Using the second capability on the list as another example, i.e. being confident and feeling empowered, one could argue:

> **If** engineering education empowers students and enhances their confidence, **then** engineering graduates should be confident to use their individual and collective agency to advance social justice.

The same principle applies to the remaining capabilities.

It is interesting to note that although I present this summary of valued capabilities and functionings as one cohesive list, these categories were not evenly distributed across the data. That is, transcripts from focus groups with South African and Zimbabwean students were more often coded with the terms ‘confidence’, ‘resilience’, ‘empowerment’ as compared to the transcripts of the focus group discussions with German students. On the other hand, ‘problem solving’ was equally prominent across the data, while ‘personal development’ was more common in the German data.

Because the intention is not to dichotomise the perspectives but combine them, the identified capabilities and funtionings are summarised together and illustrate the value of combining global South and global North perspectives on engineering education. If the data only comprised of global North perspectives, functionings such as being resilient and having a sense of affiliation would not feature in these findings. Similarly, had only global South perspectives been considered, the findings would lean more heavily towards concerns about employment and employability. Considering both perspectives clearly provides a fuller and more nuanced understanding of the various reasons students decide to pursue engineering, what they are able to gain from engineering education and how this is linked to their potential to become public-good engineers.

The next section looks at students’ perceptions of the role of engineers in society, and reflects on the connections between these perceptions and the students’ aspirations, motivations, capabilities and functionings discussed previously.

8.5 Students’ views on their roles in society as future engineers

To facilitate thinking about the contributions the students would like to make to society, I gave them the example that one could sum up one function of medical doctors as that of ‘saving lives’. I then asked them to complete the same sentence for what they think engineers do, where I prompted responses from the students by saying: "One could say, 'Doctors…save lives' or 'Teachers…educate'. Help me complete this sentence, by telling me what engineers do: 'Engineers…'", at which point I waited for the students to respond.

Most responses fell within the scope of describing engineers as 'problem solvers' and people who 'fix things' or even 'run lives'. When they elaborated on their answers, they often gave examples of different areas where engineering knowledge can be used to solve problems or improve the human condition. For example, Christina (ZIM) says:

> *We're involved in making everything that everyone uses on a daily basis; from the soap in the morning to what you eat, to the clothes you put on. There's a chemical engineer in that process…down to the diamond on your finger.*

With this statement, Christina (ZIM) emphasises the different sectors chemical engineers are employed in (e.g. manufacturing, food production, and mining) and various human needs (e.g. sanitation, food, and clothing) that are serviced with the aid of chemical engineers. In other words, Christina's statement points to the involvement of engineers in catering for both fundamental human needs: "what you eat", and also non-essential needs: "the diamond on your finger".

Many responses also represent the view that engineers help improve people's standard of living, quality of life or the efficiency with which we are able to live our lives. For example, Markus (GER) says:

> *Maybe you could add like the standard of living, I mean getting more sophisticated products means also increasing your own life [quality] like having a nicer phone, or whatever people think is important to them, involves often, engineering techniques so...*

Phrased in capabilities language this means engineers do work that is concerned with creating or enhancing valued human capabilities, or in Markus's words 'whatever people think is important to them'. This articulation of engineers' role in society implies that engineers are more involved in providing solutions to problems, as society defines or sees them, rather than according to how engineers may perceive human problems. This idea is closely related to what Prof. Schneider (GER) (in the previous chapter) referred to as a problem in engineering education, namely that engineering students are taught that 'technology is value free' and that engineering is practised objectively. In many ways the students' responses suggest that they indeed view engineering as work which should be carried out objectively to fix problems in “More of a technical way, not like a social way” as Arnold explains, or simply deal with “Facts, facts, facts” in Rupert’s words. For example Phillip (GER) states:

> *Engineers make life-through technology- help to make life more efficient, I'll say.*

The emphasis on how engineers contribute to society is usually on technology or scientific methods. As Rupert (GER) explains:

> *We learn to solve problems in a particular way, but it's not like it’s better, but in a very… in a scientific way.*

Markus (GER) similarly explains that engineers solve problems in:

> *More of a technical way, not like a social way.*

At this point of the discussion, Arnold (GER) explains some differences in problem solving approaches between engineers and other professional groups:

> *I think there is a big difference because [in engineering] you just look at the parameters and then you think about how to change them, how to affect them and it has nothing to do with like social understanding between people it's just like the technical- and it's always facts, so you always know the numbers---*

Rupert (GER) interjects:

> *---Facts, facts, facts…*

Despite this emphasis on the importance of technical engineering knowledge being the key to solving problems, some students’ responses suggest that they do recognise how engineering outcomes are closely linked to human capabilities. Kurt (GER) says:

> *I think there is a social role because what the engineer is doing most of the time, it affects the social life as well. So you are responsible as an engineer to maybe reduce the CO2 from your plant or whatever, so there is some kind of social responsibility when you work on some problems.*

On the other hand, some responses suggest that engineers can do more than solve problems. Trevor’s (ZIM) view suggests that engineers also have the knowledge to protect society from harm and therefore have the responsibility to do so:

I think as engineers we're also there to protect the society because we know what's good and what's bad for the society.

Bridget's (ZIM) understanding of engineering functions in society included that engineers are there to design, create, and innovate:

When I think of engineers I think of like more of this creativity and design and you know? Just…new things into the society. So I think that's what engineers' role in society is.

Similarly, Jennifer's (ZIM) view is that:

Engineers are more, you know? Innovative; than being sort of the guys who-like scientists and stuff. I think for us, I think it's more of applying what we have learnt (…) to solve the day to day problems that we might be facing in society.

On the other hand, Christina's (ZIM) opinion is that a major part of engineers' roles has more to do with maintaining the innovation, products, or processes already implemented in society, as opposed to creating what is 'new'. She acknowledges that a general goal of engineering is to improve things, but she pays equal attention to the fact that engineers' work is often about keeping things in place that have already been implemented. She says engineering is about:

Improving and maintaining. A lot of engineering is maintaining what's already there.

Likewise, some student's responses suggest that a major role of engineers is to correct, adjust, or realign past engineering solutions. Sandra's (ZIM) view indicates her acknowledgement that engineers are accountable for taking part in creating processes or products that pollute the environment. She also refers to '<u>our</u> engineering actions' as opposed to simply saying 'engineering actions', which indicates that she identifies with engineering professionals and that she is expressing a sense of shared responsibility:

I think there's still a lot to of, if I can say damage control, like if we look at emissions and try to normalise things again (…) because of the consequences of our engineering actions, yeah.

Towards the end of one of the focus group discussions, Arnold, Markus, Rupert and Kurt (GER) joke about how engineers destroy the world, only to save it. I commented on the irony of their joke, to which Arnold replied:

> *Well, yeah, it is [ironic]. I mean, many problems we are facing today are at least influenced by engineers I mean maybe they didn't know better, maybe they are not as open minded as we are now but I mean carbon emission is often done by industries and industries are done by engineers so sometimes I think we have to solve problems other engineers initiated before.*

Likewise, Christina (ZIM) states that she has often come across information or heard opinions that a lot of environmental damage has been due to engineering outcomes:

> *What I've heard often from the older generation is chemical engineers are responsible for a lot of degradation right now-a lot of stuff that's gone wrong in the world; so we think we're helping, but are we really helping?*

Christina's powerful question shows that she is critical of the assumption that what engineers do, necessarily helps or 'fixes things' or 'solves problems'. Both Christina (ZIM) and Arnolds's (GER) views show that the students are able to pose questions that challenge some assumptions about the role of engineers in society. Their views show that although they value possessing knowledge that enables them to solve problems, they do not take it for granted that engineering outcomes always achieve this. Students' rationality surrounding this matter shows critical thinking and reflexivity in action.

To conclude, it is clear that students largely perceive engineers as efficient problem solvers, who through technology and science are able to apply specific technical knowledge to attend to a variety of basic human needs, desires, or pressing challenges in creative and innovative ways. The role and function of engineers in society was described with phrases ranging from 'fixing things' to 'protecting society' which shows that the students recognise that engineers can apply their knowledge to non-living 'things' to affect changes in human life. With regard to protecting society, emphasis is placed on the issue of negative impacts on the environment. There is a keen awareness amongst the students that some engineering outcomes cause damage to the environment, thus creating new problems from the very solutions they implement (these are issues that are closely tied to questions surrounding sustainability, which are addressed in the next chapter).

8.6 Summative discussion

Findings presented in this chapter dealt with students' aspirations, their motivations for studying engineering, and what they value most about the process and its outcomes. It is important to note that there were no obvious differences between student responses across the various engineering disciplines (i.e. industrial and production engineering, and process and chemical engineering). Not surprisingly, the capability for employment emerged the most common valuable outcome of engineering education across the data, but the students aspire towards very different career paths. While some students would like to continue with conducting research within universities, others are keen to begin their corporate careers in the engineering sector or would eventually like to become engineering consultants. In addition, while some have decided that they would like to work in companies that are explicitly pro-sustainable development, others feel that they can do positive work in companies that are not primarily geared towards sustainable development.

The discussion on students' motivations for choosing to study engineering highlighted the importance of asking questions about students' educational capabilities instead of simply looking at their functionings, if one seeks to understand how higher education is enabling them to thrive. Questions related to students' motivations behind studying engineering were important to ask in order to try to establish the extent to which their study choices were intrinsically motivated as this information can be used as indicators of valued educational capabilities. The findings revealed that some students' decisions were made in a manner that seems somewhat arbitrary. For example, some students wanted to study something that was rooted in mathematics and science because they performed well in these subjects in high school. At the same time, they did not want to be perceived as 'nerds' so they opted for engineering studies instead of a degree in e.g. Physics. On the other hand, a few students were primarily concerned with shortlisting jobs with high salaries, with one student saying that he just 'googled' *top starting salary* to review his career options. A number of students initially wanted to study medicine, and ultimately decided on engineering because their preferred choice was not available at their university. The most important indication from these findings is that only one of the students primarily went into engineering studies out of direct interest in the engineering profession per se. I discussed the potential problems this poses for developing public-good engineers and argued that engineering education should provide students with opportunities to develop appropriate engineering identities and dispositions towards technology.

Having discussed students' motivations for studying engineering, my discussion moved to students' aspirations, where it was revealed that valued functionings include being confident, being resilient and fearless, as well as being problem solvers. Based on the interpretation of students’ articulation about what they appreciate most from their studies, it appears that some of the capabilities that underlie valued functionings include the opportunities to learn ‘how things work’ and how to solve problems as well as opportunities for personal development and prospects to work in diverse industries. These capabilities and functionings represent what future engineers’ contributions to society might be.

The last section of this chapter considered how students perceive the role of engineers in society and it shows that students generally see engineers as problem solvers. Also, students perceive engineers as contributors to positive change in and valuable benefits to society. However, there are mixed views on the value of engineering solutions to society, due to the negative impacts of engineering activities on the environment. This dilemma is explored in further detail in the next chapter, which addresses questions on the appropriateness of engineering solutions for human development. The next chapter also explores sustainability, its teaching in engineering education, and the extent to which students perceive their capacity to functions as agents of sustainability in the future.

Chapter 9

The reach of engineering education in teaching for sustainable human development

9.1 Introduction

The SDGs offer a new vision of education (Boni, Fogues, & Walker, 2016). Goal 4 of the SDGs refers to education with the following statement: "ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" (UN, 2014: 10). There is one target proposed for monitoring SDG 4 that is related directly to ESD:

> By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through *education for sustainable development* and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development (UN, 2014: 11).

Keeping this in mind, this chapter brings to light questions about the reach of engineering curricula and pedagogies in teaching students values associated with sustainable development. Data is drawn from the student focus group discussions and the lecturer interviews. Similar to the previous chapters, my discussion constantly draws on both the views of participants from Germany and South Africa.

What is different about this chapter is that it contains a combination of students' and lecturers' voices, as opposed to the previous chapters which looked at the findings for each group of participants separately. To begin, the chapter describes the role of engineering curricula in teaching sustainable development and then explores the challenges of teaching sustainable development as a fixed concept. Thereafter, the chapter discusses students' understandings of this concept and its implementation in engineering praxis. Students' views on their ability to advance sustainable development in their capacities as engineers in the future are also discussed, before revisiting the capability approach and drawing conclusions.

9.2 Learning about sustainable development through the engineering curriculum

One of the criteria used to select the university case sites studied in this project was the institutions' commitment to, and explicit engagement with the topic of sustainable development or sustainability in their engineering curricula.

A good example of a course that is dedicated to creating awareness and broad understandings of issues related to sustainable development includes 'Sustainability and Organisational Leadership' from Universität Bremen. This elective course addresses fundamental questions of sustainability from an interdisciplinary perspective, where the aim is to offer students a language and/or order system, with which they can evaluate companies' statements about, and commitment to, sustainable development. It also allows for detailed discussion of the concept of sustainability and new tools of sustainable resource management are presented to students (UB, 2013). Another example is the elective course 'Sustainability in Chemical Engineering' offered by the University of Cape Town. This course provides graduate students with an awareness of issues surrounding sustainable processes in the chemical engineering industry and an appreciation for its importance. It examines the central role of chemical engineering in achieving balance amongst economic, environmental, and social benefits and impacts arising from projects conducted by companies operating in the oil, chemicals, minerals, and energy sectors. The course also addresses related challenges of intensive agriculture and provision of water and seeks to provide a framework and a set of tools which will assist the process engineer in providing rational input in terms of sustainability into the decision making process (UCT, 2015a).

The courses mentioned above are illustrative of the manner in which themes related to sustainable development are being addressed through engineering curricula at the selected universities. It is apparent from the empirical chapters that courses that deal with sustainable development questions help students gain awareness of, and interest in, factors that influence the natural environment. Such courses also show potential to stimulate students' critical thinking. However, the fact that they are usually offered as electives limits possibilities for *all* students to learn from them. For instance, Phillip (GER) gives the example of the course 'Industrial Ecology' that he studied, stating that one learns about the complexities of factors that need to be considered when aiming for sustainable development in car manufacturing. He provides the example that switching to electric cars, cannot be a solution in itself, to the problem of pollution caused by motor vehicles, because one would first have to consider the source of electricity used to fuel electric cars. He attributes such knowledge to the Industrial Ecology course. He says:

> *I find it good that one has courses like Industrial Ecology where you learn how complicated it [sustainable development practice] is (...) One cannot say 'okay we're switching to electric cars, and we'll get that electricity from coal fired power plants'.*

That wouldn't make any sense, and that is something one does learn from such courses.

Phillip (GER) states that such considerations have to be borne in mind by engineers when carrying out their work. However, his response also indicates that sustainable development problems are not considered by some engineers, implying that ideals of sustainability do not necessarily characterise the value systems of all engineers:

I mean, one does have to consider this question [of sustainable development] throughout the whole process (…) [but] there are those who say: we're doing it that way, those who say it is important and those who say it isn't.

If ideals and values of sustainable development do not influence engineers' values, and if they are confined to elective courses, good as these might be, this is not conducive to widespread public-good engineering. Therefore, an important question is: To what extent do universities instil values associated with sustainable development in their engineering students (beyond electives)? Such values would include those aligned with public-good engineering e.g. that engineering should enhance valuable capabilities and functionings for communities and promote *homo reciprocans* instead of *homo economicus* approaches to solutions. While some students do feel that their values have shifted as a result of engineering education, others are less convinced that this is a result of their studies. While students such as Phillip (GER) quoted above, suggest that there are courses that enlighten and perhaps inspire students to be agents of sustainable development through their professional work, other students suggest that this remains a personal choice, which the universities cannot necessarily teach. As Anna (GER) states:

I think it is in some way a personality thing, but I do think that, I mean it's often said that this is ecologically better this way, or these are the consequences for the environment… that is said in our studies. And maybe it gets embedded in your mind that way, but it also depends on the person, I'm sure there are other people who don't live their lives according to sustainability.

Similarly, Lisa (GER) says that learning from subjects that are related to sustainable development prompts students to think about the role of engineers in development more carefully, but her response also suggests this may be the limit of the effect of such courses:

I think it does result in us reflecting a bit more on the topic, but there are people who think well, maybe- not that it's complete nonsense-but rather see it differently, so it's not every engineer who is then brought up to be sustainable.

Likewise, Markus (GER) attributes a lot of his knowledge on sustainable development to courses offered in his engineering programme in the university:

Yeah, like in this general studies I mentioned before, I think there were two subjects which were about sustainability and renewable energy and everything like that, so we learn a lot.

While some students were keen to say their engineering studies had influenced some of their values, other students ask if such changes are due to their education or due to other factors. The passage below, which is an excerpt from a German focus group, illustrates this debate well:

Kurt: *When I started studying, I thought when I finish my studies I will buy the biggest car, but now it [has] changed, so now I think a small useful car is better.*

Rupert: *But I don't know if it has anything to do with your studies maybe it's just a change of your life that you think differently about it, maybe. Maybe it's not because of the engineering part.*

Markus: *Yeah, I must say I think during our studies we learn a lot of how things work and as soon as you think about how things work you think about 'what does it mean to me?', and I think that starts the progress to think about sustainability, yeah so I would agree, yeah.*

Rupert's (GER) comment, challenges the notion that engineering curricula shape students' values surrounding issues related to sustainable development. Similar doubt is apparent in responses from students who feel that sustainability principles are underpinned by values that cannot necessarily or explicitly be taught through higher education. Through the eyes of some students, the media and the state or politics, were often referred to as the main drivers of a sustainability agenda. Arnolds's (GER) words imply this, where he says that concern for sustainability is:

(...) maybe personal and influenced by the media and politics-what's good and what's not good.

Arnold's (GER) statement implies that the media and politics are co-teachers of sustainable development and that this ultimately shapes an individual's affinity for, or indifference towards, sustainability. It is clear that students supplement what they learn about sustainable development through their studies, with messages portrayed in the media. What is interesting to note about students' views on these conduits of knowledge about sustainable development is that information from both the university and the media is often perceived as ambiguous. It is not clear whether the ambiguity stems from the fact that the term itself is contested and can be used in different ways, or whether it is because there are mixed messages about what sustainable development is.

What is perhaps most important to note is that students are engaging in the process of questioning the way things work and what that means for them. This signals that some students are engaging with issues of sustainability in personal ways. This is important because it shows that students are exposed to knowledge about sustainable development in a way that does not result in only one way of understanding sustainability. It also signals the potential for engineering education to provide students opportunities to deepen their commitment to sustainability in ways that they have reason to value. Nevertheless, most students' argue that they do not learn the 'how' of sustainable development or sustainable engineering. Anna's (GER) words indicate this, and suggest the onus is on the individual to take initiative and inform themselves on what sustainable development looks like and how to implement it:

I also think (...) it's not being communicated properly [through media] because we're also not told: 'you should save on heating' they say: 'coal should be used less'. So, actually, I think in our studies it's also not well communicated, just the theory what sustainability is [is taught]. But how sustainability can be implemented, I find is not really taught in the studies. That is more of a personal interest thing I would say.

Likewise, Trevor's (ZIM) response suggests the bulk of what he knows about sustainable development comes more from his general personal interest and observation, rather than as a result of a taking a course with sustainability content. He says that he learns about sustainable development:

through general awareness, reading and also some journals and people speaking at maybe conferences (...) so my knowledge is based on general awareness, getting to hear around, and also reading.

Similarly, when talking about the value of elective courses, some students think that they do not learn much 'know how' from courses geared at developing soft-skills. Instead, they feel they learn a combination of soft-skills from project work. Communication skills are often highlighted as an outcome of project work:

Christina: *We go through a lot of group work, we communicate all the time with each other, with the class like I can meet like ten different people in one day because I have a project*

Valerie: *And everything you do you need a presentation really*

Penelope: *Yeah, everything is group work, everything is a presentation…these communication courses actually don't help that much.*

In the same focus group from the University of Cape Town, students debate the value of elective humanities courses. While Christina (ZIM) sees the value in courses such as sociology and anthropology for the research she is conducting for her masters, other students argue that the range of elective courses is too broad, or that they cannot find a course which they feel has added value to their engineering knowledge:

Christina: *I did Anthropology, Sociology and Mandarin as my electives and I've seen that I've used a lot of knowledge from Anthropology Anthropology and Sociology, for the study I'm doing at the moment, and just looking at that connect between being an engineer and using the social aspects to design technology…and I don't see that a lot in engineering, particularly in chemical engineering education, so maybe they need to advise better in terms of the soft skills you should be attaining, to solve problems holistically.*

Penelope: *Or maybe they should like in the programme incorporate those, because if they give you two electives, that could literally be anything. People end up taking statistics, or whatever is easiest. Things that are easy or don't develop your soft skills to begin with.*

Valerie: *Or what's available between 12:00 and 14:00…the easiest one that fits into that period.*

Molly: *Because you don't have time to do other subjects that aren't gonna bring you anything…it's like a whole bunch of excess knowledge that's never meant anything in my life.*

To summarise, findings suggest that 'sustainable development' courses are conducive to building appropriate propositional engineering knowledge (know that) but, appear to do little for students' procedural knowledge (know how).

It is clear that students appreciate the knowledge they gain from courses offered by the university, which address sustainable development problems. However, some students questioned the extent to which their values were being shaped by this knowledge. However, the fact that students engage in the process of questioning 'the way things work' and how best to make sense of sustainable development indicates personal ways of engaging with issues of sustainability. This suggests that engineering education generally, or SD courses specifically, may shape students' values towards sustainability in implicit ways. It is also clear that the engineering curriculum is not the only source of knowledge that students draw from to formulate understandings of sustainable development. Sustainability courses seem to provide a foundation upon which other sources of information (particularly from the media) are interpreted, and made sense of in order to complement students' comprehension on the topic of sustainable development.

It appears that engineering curricula are effective in contributing to students' intellectual or cognitive understanding of sustainable development, but courses on sustainable development on their own have limited reach in shaping students' values. However, the purpose of ESD is to allow students the opportunity to be better informed about various aspects of development, and encourage them to re-evaluate their role and responsibilities in the development process (UNESCO, 2005). Particularly in engineering education, ESD also challenges students to re-evaluate their understanding of broader social issues and their capacity to construct appropriate solutions for human needs (Cruickshank & Fenner, 2007). Therefore, if engineering students' understanding of sustainable development is limited to intellectual comprehension and their values are not meaningfully influenced by their studies, engineering education falls short of enhancing students' opportunities to function as agents of sustainable development.

It thus also appears that, following advocates of ESD, university leaders, faculties and students should introduce sustainable development into all elements of engineering education to safeguard sustainable development as its golden thread. This requires universities to explore how academic courses interact with other knowledge sources and individuals' personal experiences in the formation of sustainable development values. This implies that measures taken by engineering education institutions to teach sustainable development, should focus on both the content of courses that are designed for this purpose, as well as who is teaching this knowledge. Engineering educators clearly have a responsibility to help instil values associated with sustainable development in their students, regardless of the course they teach.

The next section explores this aspect further and considers the values that underpin engineering lecturers' understandings of sustainable development and how they perceive its teaching.

9.3 Teaching 'sustainable development' as a disputed concept

The discussion in this section shows how some lecturers perceive complex interactions between societal forces that fuel their uncertainty of the meaning of 'sustainability' and therefore 'sustainable development', which creates difficulty in teaching the concept as a fixed ideal.

In one of her responses Prof. Schwartz (GER) suggests there is a lack of consensus about the meaning of sustainability, implying it is almost impossible to define it because our moral judgements of what is sustainable changes depending on a number of complex variables. The questions Prof. Schwarz poses are good examples of the kind of questions engineering students should be grappling with in order to exercise critical thinking towards notions of sustainable development. She asks:

> *What is sustainability? What does that mean? Does that mean that we do not use any energy anymore to keep the planet stable? Do we all want that? Does that mean that we do not produce any garbage anymore? (...). The question 'what is sustainability?' is not really answered right now.*

She goes on to give some examples of what could be considered as sustainable practices in agriculture, manufacturing, and design; in each case highlighting the difficulty in labelling something as a sustainable process. She uses the example that arable land is being used for growing crops that are used in bio fuel, instead of growing crops for human consumption, citing this as a good debate for thinking about the meaning of sustainability. She argues:

> *We are using bio energy, and killing places where food could grow…the question is very difficult to answer, 'what is sustainability?'*

Prof. Schwarz's responses show that she believes sustainable development is a multifaceted and fluid concept. This implies that she would rather teach her students to think critically about approaches to sustainable solutions, rather than promote the idea that one particular solution is necessarily more sustainable or beneficial to society than another.

On the other hand, in defining sustainability or teaching what sustainable development means, Prof. Smith (SA) explains how chemical engineering might lend itself well to exploring ways in which the environmental dimension of sustainability can be addressed through teaching aspects of cleaner production or waste management systems. She does however note that it is very difficult to engage students deeply with the broader dimension of sustainable development that is concerned with societal issues:

> *(…) at the post graduate level they use life cycle analysis and so on, so very much a chemical/process engineering kind of take on the notion of cleaner production. So we're not debating so much the issue of like social inequity which is a part of the broader definition. Given [that] the kind of discipline here (chemical engineering) is less an area for serious engagement in that sort of thing, you know as compared to your course in sociology.*

Concern for neglect of the social dimension of sustainable development in engineering education is shared by Prof. Jones (SA) who speaks against the shallow use of the term 'sustainability' implying this is done inappropriately and takes away from the impact of the word:

> *I think the term sustainability is used too loosely and applied too often to think that just basically means commercial sustainability. And in the university specifically in a setting in South Africa tends very strongly towards the commercial sustainability aspect of it. In engineering, in chemical engineering, I don't want to speak for the whole university- and that is by virtue of the fact that the interested industry, the chemical process industry influences very strongly what is going on in chemical*

engineering, by research contracts that they give, by stipends that they give to the students and also by being on the advisory boards of the committees that are set up.

Prof. Jones's (SA) concerns allude to the idea that there are structural constraints imposed on university departments, due to the financial ties certain institutions may have with companies that contribute to funding the university. He argues that such situations allow industry to dictate universities' commitment to sustainable development, or at least influence universities' stance on the issue of sustainability. It is interesting to note that concerns about academic freedom and autonomy are not only related to the issue of funding from industry, but also the impact state funding has on the governance of universities.

Similar to answers on how to teach transversal skills (discussed in chapter 7), many responses from lecturers pointed to the curriculum for answers on how to teach 'sustainable development'. For example, Prof. Bremer (GER) refers to courses that can prompt students to think about the social, environmental, and economic aspects of engineering outcomes, saying that they go a long way to get students thinking about issues surrounding the concept of sustainability. He also suggests that there is a level of what Connor et al. (2014) refer to as 'disciplinary egocentrism' amongst engineering educators, which can be defined as the lack of student or staff readiness to engage in multidisciplinary knowledge or apply alternative teaching and learning approaches to engineering. Prof. Bremer (GER) explains:

> *The course 'Technical Assessment' stems from a critical stance towards the consequences of technology. As such, this is a course which lends itself to that excellently.(...) We need lecturers, and as such, also professors who say we want to deal with questions and problems of technology, and consequences on society, consequences on the environment and so forth-unfortunately there are too many hard liners amongst us engineering professors who say we don't need that, I think that's a catastrophic mistake.*

Contrarily, Prof. Kleid (GER) argues that teaching sustainability through elective courses is inadequate explaining that issues to do with sustainable development have to be integrated throughout engineering curricula, and in the curriculum of other education programmes to explore what the principle of sustainability might look like when applied in different disciplines:

One then has to ask what is the purpose of an exclusive course? because it can't be about telling people that they can decide to be either pro or anti sustainability-that's total rubbish (...) these issues belong in the regular curriculum, in the course content, not as here an extra course, there an extra course, because then you have a lot of extra courses, and in the end you don't know what it's about anymore (...) we have to communicate what influences what, for example the topic sustainability in this field, in that field, and and and…that belongs in the message.

On the other hand, Prof. Hunter (SA) posits that there is enough awareness of sustainable development challenges created through the media, which takes away the pressure in engineering programmes to do this for students. Instead, he argues that the bigger challenge lies in creating more awareness of these complex issues amongst older engineering educators. His response also indicates his reflection on the fact that sustainability issues in the curriculum interact with sustainability debates in the public domain. As mentioned previously, there should be more attention focused on the nature of this interaction if we are to understand how values associated with sustainable development are best formulated:

I think all over the world today in engineering education- you don't need to tell young people that they have got to look after the environment. They see it in the movies they read it in the newspaper; the world is full of the story of environmental impacts and the green economy and so on. And in fact my view is that the older generation such as myself need to play catch up because when we started engineering we didn't worry about that.

Similarly, Prof. Jones (SA) is of the opinion that engineering students come to the university already having the necessary awareness and values in place, arguing that although specific ethical values may be difficult to instil through teaching technical courses, it is something towards which universities should strive. He explains that in his experience students come to the university and enrol in engineering programmes with bold intentions of helping to 'save the world' through sustainable engineering outcomes, saying that such ambitions are:

(...) kind of simplistic [naïve]…but the value is there, you now just have to build that value and bring more sophisticated understanding that we're not 'saving the planet', that will take care of itself, we're saving humanity, that's more of the challenge here. So you can take that good intent all the way through your technical work all the way into detail all the way out of detail back to the big picture.

By contrast, Prof. Marco (GER) argues that this type of knowledge can be learned later in life, and that universities should maintain their focus on imparting technical skills, because it is the only space in which students can perfect foundational engineering knowledge:

> *However still the vast majority of what the university provides is fundamental science and technical knowledge because otherwise-where do you get that? It is in my opinion easier to acquire the skills required to work in sustainable, or human development engineering later in your career rather than acquire the technical knowledge in your later career, this is exceedingly difficult.*

On the other hand, Prof. Kleid (GER) speaks of the importance of interdisciplinary knowledge explaining that he is a proponent of such approaches to engineering education:

> *I myself, have, here in Bremen, before I got my professorship, as a planner of the study programme Industrial Engineering; and as a result I am a strong believer of interdisciplinary knowledge, which engineers need. So I do not represent one who looks exclusively at engineering sciences, I look very much at the intersections, and I regard it important that we, educate people who are capable of on the one side, to develop technology and at the same time to understand the consequences of technology, and who are also capable of communicating technology.*

Correspondingly, Prof. Schwartz (GER) emphasises the need for engineering students to be cognisant of the fact that technological advancements in themselves are not necessarily pro human well-being or sustainable development on the one hand. On the other hand, she also teaches her students that one cannot look at technology as a bad thing per se. She also argues that the state and society are stakeholders who should be making decisions on some fundamental questions about the pursuit of development through technology. She says:

> *When people say 'technology is bad' I say okay. How is your life today? What is your medical supply? What is your dentist doing? It's engineering. Yeah? Why do we grow so old? How come so many children survive the first three months even those with heart diseases. What do you think are the machines that keep them alive during the operation?*

Prof. Schwartz (GER) poses these questions to illustrate the good that can and does come from technological advancements that result from engineering and indicate the tensions that arise from this. At the same time, these words counter popular arguments against technologies that do little to improve human lives in just ways. Her words also serve as a reminder that technological advancement is not necessarily synonymous with development.

In the quote[37] below, she explains her understanding of the role of engineers in society using an analogy on different levels of participation for a particular cause, arguing that the engineers' assignment is that of being active agents of positive change in society:

> *And when I tried to explain this I say we have different roles in society, there are people who climb on the trees to say save the trees, and that's one role. And the engineer can say what can I invent that I do not need them [trees] anymore for my product? So I wanted to be the one who thinks about the better solution, the best solution instead of just saying I'm against it. Of course it's important that people say I'm against [something] but that's not enough. That's just the beginning. It doesn't help us to be against everything. We've got to be for something. So the question is what is it for? And that's from my point of view the engineering subject. To be 'for' something.*

To summarise, while some lecturers seem confident that the media or engineering curricula adequately address sustainable development concerns, other lecturers call for more interdisciplinary engagement with the subject and challenge themselves to prompt students to think critically about the meaning of sustainability. This difference in the views of lecturers is important to note, because it shows that engineering educators have different value sets that underlie their conception of teaching and of sustainable development. It is apparent that teaching sustainable development comes with the challenge that the concept itself is multifaceted and fluid, making it a difficult subject to teach across engineering disciplines.

A study that offers empirical evidence on the effects of teaching sustainability as an elective course shows that most engineering students, after taking a course on sustainable development, focus on the technological aspects of environmental sustainability, and neglect the social/institutional aspects (Segalás, Ferrer-Balas, & Mulder, 2010). This hypothesis suggests that addressing sustainable development through the curriculum alone may result in students developing narrow understandings of the concept. This conclusion supports findings that indicate that there is no single approach or formula for implementing ESD curriculum

[37] This quote is used on page 167 as part of the discussion on developing an engineering identity. It is repeated here because of it is also a good example of the kind of questions one might ask when thinking about the instrumental value of engineering, particularly in relation to sustainable human development.

change that has been found to be effective (De La Harpe & Thomas, 2009) and bringing about such change is challenging. However, if students' engineering knowledge is combined with non-technical skills such as open-mindedness, critical thinking, effective communication and collaboration skills, they are arguably in a better position to make appropriate judgments about sustainable development.

Therefore, as opposed to gearing efforts towards teaching fixed ideas about sustainable development, more attention should be focused on making sure that students are able to engage with ideas of sustainability critically and personally.

The findings therefore also suggest that more attention should be focused on exploring engineering pedagogies in relation to sustainable development. In particular, the values that frame lecturers' understandings of sustainable development may have an important influence in shaping students' perceptions of the concept. For these reasons, it is important for universities to provide opportunities for engineering educators to develop values that are aligned with social justice goals. An example of such a value is public-good engineering.

9.4 Students' understandings of sustainable development

In the focus group discussions with students, the intention of questions surrounding sustainable development was to establish the various ways in which students understand the concept and how they articulate their understanding. Also explored in these parts of the discussions was how much of their knowledge on sustainable development students thought could be attributed to their studies, as well as their views on their perceived capacity to function as agents of sustainable human development once they are practicing engineers.

When asked what came to mind when they heard the term 'sustainable development' or 'sustainability' responses such as: "the environment" or "I think about the future" and "managing the resources" were very common across both groups of students. Even more common were utterances that were almost identical to the WCED's definition of sustainable development i.e. "development that meets the needs of the present, without compromising the ability of future generations to meet their own needs" (WCED, 1987:43). For example, Anna (GER) states that:

> *Sustainability means I only use resources in a way that there are enough for other generations to come (...) that resources are used in a way that future generations can also use them in the same way that we do.*

Likewise, Rupert (GER) explains his understanding of the notion of sustainable development with the words:

> *It's like you give the next generation the chance to live a life like we do…same chances, same resources.*

At times, the answers of the students on the question of defining sustainability were nuanced. Some students were even reluctant to say sustainability meant any particular thing. Wendy's (ZIM) words also indicate that discussions about sustainability have been integrated in the curriculum to some extent. She says:

> *It's been an ongoing discussion since first year…it keeps changing. The definition keeps changing.*

This is also an indicator that sustainable development is a topic which is being covered well in the curriculum. On the other hand, Christina (ZIM) explains that sustainability:

> *Is a holistic approach to understanding what the need is, and when you bring in a solution that solution should be self-reliant in some form, from a social end, from an environmental end, [and] from a technology end. That's what I view as sustainability.*

Students' responses also show that they are aware of the difference between how sustainable development is defined and how it is implemented. This indicates a distinction between students' perception of the concept on an intellectual level, and what the practical implications of this ideal are in engineering practice. For example, when Penelope (ZIM) responds to the above quote she comments that Christina's (ZIM) understanding is based on a 'text book' definition, to which Christina responds:

> *Pretty much…but the dictionary definition compared to what actually happens in reality is completely different. So I'm still trying to figure it out.*

Furthermore, the students share the rather bleak outlook that engineering efforts and innovations will always prioritise economic profit above the other two pillars of sustainable development. Similar to some lecturers' views on the glib use of the term, the students from University Of Cape Town in particular talk about how sustainable development is used as a marketing gimmick in industry:

> Penelope: *It's just thrown around: green! sustainable!*

Valerie: *And then you can just mark the price up because you have something that is 'green' or 'organic'(...) they'll capitalise on anything.*

Christina: *It always goes back to money.*

Based on these views, it is clear that the engineering students are being made aware of, and taught about various aspects of sustainability and sustainable development through their study programmes. The students showed that they grasp the concept of sustainable development with references to commonly used definitions in sustainability discourses. The most important observation across the data is that the discussions on this particular topic were almost constantly in the form of a debate, as opposed to a discussion characterised by consensus. These debates showed that the students regard sustainable development as an ever-changing concept, although they could articulate popular definitions of the term very well. The debates also suggest that the concept is valued by the students - at least enough to be the basis for debate and discussion. Also, students' have a keen awareness of the ways in which the three pillars of sustainable development (the economy, the environment and society) 'compete' against each other, although this should not be the case. Ideally, the longevity of all pillars ought to be safeguarded. The students' views clearly indicate that they believe that the economic dimension of sustainability is over prioritised at the expense of the other dimensions.

In the following section, students' suggestions on what engineers can do to address this problem are outlined and their perceptions on the role of engineers as agents of sustainable development are provided. Again, discussions on this topic mostly took the form of debates across both groups of students, indicating its complexity.

9.5 Students' perceptions on engineers as agents of sustainable development

Students' views on their roles in society as future engineers suggest that they are sceptical about their effective power to function as agents of sustainable development. There is often concern expressed about limitations imposed on engineers by industry and economic constraints, which students fear will hinder their ability to reach the ideals of sustainable development. For example, Markus (GER) states:

We haven't been in industry and I think there- it's different there, because it's much more about money than about your idealistic thinking.

On the other hand, Kurt (GER) believes that engineers' knowledge and skills gives them effective power to influence decision makers in industry in ways that can gear more efforts towards sustainable development. He also argues that this is more likely to be the case, if more engineers end up in managerial positions within the corporate sphere:

> *Because you have a technical background and you can explain and see the possibilities, and if you talk to the decision maker then you can still influence whatever is planned. And I think in the industry, even like the powerful people sometimes are engineers.*

On the contrary, Lisa (GER) has apprehensions about limitations imposed on engineers to exercise their agency in large corporations. She argues that it is easier for engineers to advance sustainable development values in small to medium sized enterprises or companies that explicitly focus on environmental sustainability:

> *I would rather work in a small to medium sized company where you can still actually influence something, and where it's about making people's lives easier through sustainable development and so on but also to unburden the environment so like, maybe renewable energies, maybe electric cars or that kind of thing.*

Kurt (GER) also sees this issue in the same fashion but emphasises that the problem lies in too many decisions related to sustainable development having a political dimension. His words describe engineers as pioneers of change, where the mandate of that change is predetermined by the state:

> *I think a lot of it is more from the politics but the engineers are the people who- like if politics says there is a power plant and we have to reduce the CO2-then the engineer has to think about how to do it. So the engineers are the people who are trying to reach what politics decided before.*

Arnold's (GER) opinion is similar, and his views allude to the fact that *homo economicus* principles are over emphasised in industry. He argues that this is the reason why engineers do not have the voice they should. He says:

> *I mean you would have to convince the people who earn a lot of money with their company, and if that income is decreased it's really hard to convince someone to do research into renewable energies and stuff like that, and I think often, for example, I*

think they [politicians] don't even know what is the potential of engineers' techniques, what is possible, what is not; and so I think there is an influence, but as I said before as long as society and politics don't want to like, change the way we live, it won't really be possible.

Again, the intricacy of various aspects involved in determining who gets to decide on the pursuit of sustainable development agendas is highlighted. Below, Rupert (GER) explains the cyclic result of engineers being 'fixers' of what industry identifies as problems, asserting that the very efforts engineers in the past have geared towards development have contributed to current challenges:

I mean many problems we are facing today are at least influenced by engineers, I mean maybe they didn't know better, maybe they were not as open-minded as we are now, but I mean carbon emission [are] often done by industries and industries are done by engineers. So sometimes I think we have to solve problems other engineers initiated before.

Rupert's statement above sparked a debate among the students concerning accountability for creating technologies, processes and products that have in the long run not benefited humanity in a just way:

Markus: *Yeah, I would say it's more the company itself not the engineer, I don't know…*

Rupert: *Yeah maybe it wasn't the intention but…*

Markus: *Yeah, well, I don't know…*

Arnold: *But normally engineers are not the people who make the decisions…*

The perception that 'engineers are not the people who make the decisions' is echoed by most students. Wendy (ZIM) explains:

I think the power is really not in our hands because it all boils down to the economic aspects of like, if the company says 'we have a budget of this much' you have to work within that budget or else…I guess you lose your job.

Wendy's statement reflects some fears about the perceived potential consequences of not conforming to company demands. However, engineers are not simply employees whose only social responsibility is to obey hierarchy. In extreme cases, blowing the whistle and taking the risk to bypass their obligation of loyalty towards their employers may be necessary (Didier, 2010). While in other situations, exercising agency for positive change will require engineers to contribute to improving the structures in which they act, in order to turn them into more fair and responsible institutions (Didier, 2010). This point of view fits well with a definition of ethics as 'an aim of the good life with, and for others in just institutions' (Didier, 2010: 186).

Unlike Wendy (ZIM) Jennifer's (ZIM) opinion alludes to the notion that engineers remain a powerful professional group in contributing to human well-being, sustainable development and social justice. She argues that engineers have the responsibility to help strike a balance between all three pillars of sustainable development (economy, environment, society):

> *I think we have the power in our hands to determine the outcome of every process- so whenever we're going to design something we can still design something that has like a lot of economic benefit but also has advantages to the society because in the end it's [not good] for us to have all this benefit for the elite and then ignore the rest of the people (...).*

On the other hand, Christina (ZIM) questions the ability of engineers to help 'strike a balance' between the three pillars of sustainable development again expressing concern about the voices of engineers not being heard:

> *But the question is: how effective are you as an individual in that company if you want to have a say in something- do you have a voice?*

Valerie (SA) responds to this question by asking another question, which suggests that it is a fundamental task for engineers to come up with solutions within conditions that are characterised by constraints:

> *Isn't that the challenge for an engineer? To come up with creative solutions in a space where you are limited?*

Most focus group participants respond by suggesting that the spaces that exist for graduate engineers in industry are not wide enough to allow meaningful engagement with corporate heads or application of their agency. Penelope (ZIM) argues that:

If you're a graduate process engineer at Sasol you will do what they are doing at Sasol.(…) like you would have a good idea to say reduce emissions by this amount but they'd rather get a management consultancy firm to transfer the accountability and get them to do the ground work, so the question is: how much say do you have as an engineer within that company to try and change [things] you know? I don't think we have that much of leverage.

Some students argue that engineers can make incremental changes in the way that they carry out their day-to-day work activities, but the overriding sentiment of students' views is summarised well in Peter's (SA) words, who says:

In most cases financial wise you can try and improve the process in terms of emissions and all that but in most cases if it's financially better off and within the regulations of the government, that's [all that matters].

The profitability of sustainable engineering ideas formulated to take on challenges related to reducing carbon dioxide emissions is often cited as an example of the financial constraints within which engineers have to work. For example, Trevor (ZIM) says:

Engineers face resistance especially when it comes to finances when like (…) there's a project and you see that this project is going the wrong way, and you know that it should be going [another] way, there's always that friction or resistance to actually implement the decisions that engineers would have made.

Trevor's words suggest that it is the responsibility of engineers to position themselves in the corporate spaces that allow them to make decisions that are more influential. He argues that engineers need to:

Grow in terms of learning how to get ourselves into leadership positions where we can actually be the people making the big decisions for ourselves. Because mostly you'll find the people who are making the decisions will be like from other fields like accountancy, they're the ones who are managing directors of the companies so they understand the financial flows and statements and then the engineer now would face resistance from such a counterpart in industry. So the best way would be for engineers to also learn to position themselves into very influential leadership positions so that whatever decision needs to be made, whenever a project is to be *implemented it can easily be done, because we will be talking of someone who understands better what is supposed to happen.*

Literature suggests that engineers are generally regarded highly in public opinion surveys for their honesty, integrity, and diligence (Kulacki, 1999). Also, according to Boni et al. (2012), engineers have come to regard themselves as appropriate leaders of society who can solve social problems using science and logic as agents of industrial development, whilst also showing qualities of being impartial and rational and responsible for ensuring positive technological change. Moreover engineers perceive themselves as having better aptitude to make decisions than lay people, and having a professional identity and status which qualifies them to exercise power in organizations through their capacity as technical problem solvers (Trevelyan, 2014). However, engineers are sometimes avoided in legislative processes and public affairs because of a tendency to approach subjective matters from a technical angle, where rigorous methods of objective analysis are used to make recommendations and decisions (Kulacki, 1999). This means that engineers usually have to rely on other people to deliver the results of their work (Trevelyan, 2014). This is problematic because simply finding a solution to a technical problem may not provide any value in itself; the value is only created once the technical solution is applied to result in improving human capabilities (Trevelyan, 2014). Therefore, when engineers take leadership positions in industry, they should have the capacity to balance their engineering knowledge with a keen awareness of human and social dynamics.

9.6 A capabilities-inspired, empirically informed framework for public-good engineering education

As indicated in chapter 1, literature that illustrates the contribution of the capability approach in provoking critical reflection on conceptions of sustainable development is growing (see Crabtree, 2013; Lessmann & Rauschmayer, 2013; Pelenc et al., 2013). However, as Crabtree (2013) warns, we should not blindly apply the capability approach as a lens through which sustainable development should be seen. There should also be a focus on examining the limits of our freedoms because our beings and doings have consequences which need to be accounted for, and hence need to be part of the conceptual evaluative space of our judgements on sustainable development (Crabtree, 2013).

Crabtree (2013) defines and defends a concept of sustainable development as "a process of expanding the real freedoms that people value that are in accordance with principles that cannot be reasonably rejected by others" (Crabtree, 2013: 41). By so doing, he draws in issues of morality and ethics to interrogate how individuals evaluate their actions as right or wrong, in relation to how they may affect other people. This, Crabtree (2013) argues, is important to take into account because the moral choices that we can make, and we can be blamed for, are limited by the knowledge we have. For example, carrying out an act of pollution, when there is an option to do otherwise, whilst being aware of the negative consequences that will be suffered by others, is morally wrong. Thus conceived, one could similarly judge engineering decisions as morally wrong if they are carried out with disregard for poor and marginalised communities.

Although different students gave diverse accounts of their understanding of sustainable development, there is a clear sense across most responses that they value the concept. There are also clear indications that the students are critically reflective, and that they have developed 'dialogic habits of mind' (Wood & Deprez, 2012). However, their responses do not immediately indicate that poverty reduction is valued. This does not necessarily mean that the students are indifferent to the existence of poverty, and it does not necessarily suggest that they have no reason to value reducing it. It does however show that their understanding of sustainable development does not automatically trigger thoughts of concern for communities living in poverty. Yet, it should.

To reiterate a capabilities inspired description of the goals of engineering education: Engineering education should enhance the professional capabilities and functionings of engineering graduates, provide them with meaningful opportunities to develop, demonstrate and deepen their commitment to the cause of poverty eradication, and enhance their ability to exercise agency to promote sustainable human development in society. Thus conceived, students' understandings of sustainable development indicate that the reach of engineering education in teaching for sustainable human development is limited.

This leads to a number of important questions regarding engineering education in universities. Firstly, with regard to lives people can actually live, what opportunity does each student have to explore connections between engineering curricular topics and contemporary inequities involving power, privilege, and material resources? Secondly, with regard to 'development' what effective opportunity does each student have to:

- Unearth and interrogate assumptions about development?
- Engage in critical reflection and dialogue on competing notions of human progress?

- Explore power relations and their impact on development?

Thirdly, with regard to reasoned values, do students have effective opportunities to:

- Interrogate embedded economic and political values in the engineering curriculum?
- Critically reflect on the relationship between learning, values, and engineering functionings?

If these opportunities are not effectively available to each engineering student, then the potential for universities to develop students' capacities for public-good engineering is restricted. Diagram 1 (on the next page) describes the opposite situation: what engineering education can look like, and what it can achieve for engineering graduates and do for society, when it is well aligned with, and seeks to promote sustainable human development. To develop this normative and descriptive framework, I draw from the theoretical concepts introduced in chapters 1 and 4, and inform these with empirical findings based on students', lecturers' and employers' perspectives.

More specifically, the goals of engineering education (based on findings from lecturer interviews), valued engineering functionings (based on findings from student focus groups), and dimensions of public-good engineering (based on employer interviews) are juxtaposed. The potential links between the various dimensions are suggested by the arrows drawn between and across the three columns. Based on these links, it can be seen that one goal of engineering education (i.e. enhancing students' sense of determination to pursue valued functionings and determine their roles in society) might have more significance for public-good engineering than others do, because it is essential for, and directly linked to all four public-good engineering functionings (and hence capabilities).

It can also be seen that a functioning such as applying engineering knowledge to help solve problems and challenges associated with sustainable human development, is central to a number of public-good engineering dimensions. Similarly, it is noticeable that engaging meaningfully with poor communities to ensure that engineering outcomes benefit them might be the most important dimension of public-good engineering, and that exercising agency is fundamental to this.

It is important to note that some links are not readily recognisable between the various dimensions, which necessitate asking if they should be included in the framework at all. For the time being, the framework is presented with all the goals, dimensions, and functionings of public-good engineering identified in this study, regardless of the clarity of the links that can be made between them. Although it may seem that unclear or 'weak' connections indicate the irrelevance of a goal, functioning etc., this may not be the case in reality. Therefore, until the framework is empirically tested, all its elements need to be considered.

9.7 Summative discussion

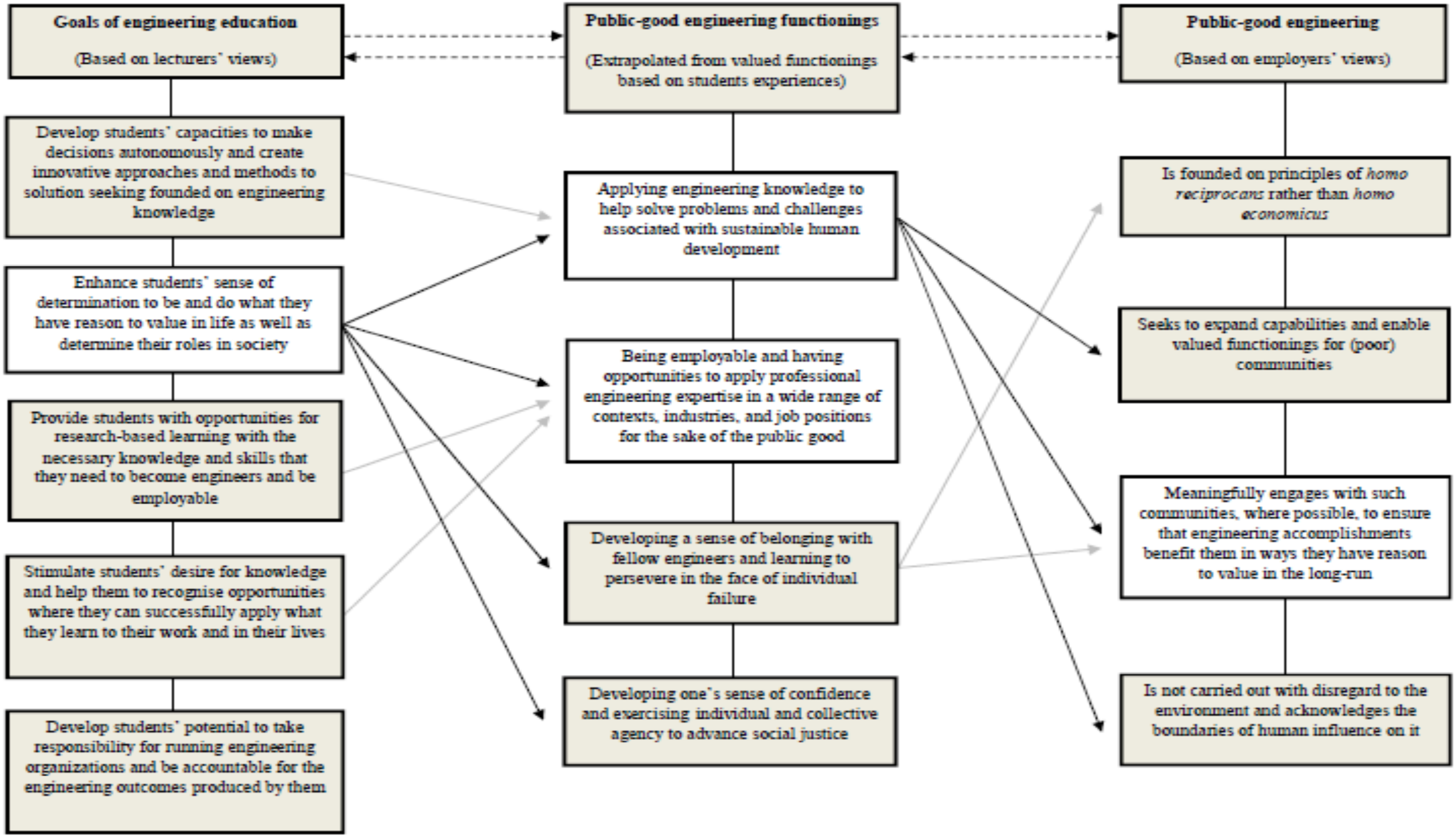
The results presented in this chapter suggest that engineering curricula at Universität Bremen and University of Cape Town provide good examples of ways in which sustainable development is addressed in engineering education through the provision of courses (such as 'Industrial Ecology') that deal with sustainability issues. However, the findings also suggest that sustainable development cannot (nor should it) be addressed solely through the engineering curriculum.

The lecturers' perspectives on teaching sustainable development or sustainability principles, and students' understandings of these concepts imply that engineers' judgements of sustainable engineering practices will vary according to what they know or believe. Efforts to embed sustainable development in engineering education therefore require more attention to engineering pedagogies, the values that lecturers bring with them into the classroom, as well as the values underpinning the curriculum. In particular, the values engineering educators bring with them to the classroom need to be explored empirically; especially in relation to their understandings of sustainable development. This could uncover pathways that universities might use to impart appropriate knowledge for future engineers to function as sustainable development agents, by ensuring that engineering pedagogies convey values that are consistent with public-good professionalism.

Students clearly value their roles as engineers; they seem to take pride in their abilities to use their knowledge and skills to solve engineering problems and have the desire to effect positive change. That is, they value engineering functionings, or *being* engineers and *doing* engineering work[38]. In addition, students see engineers as important role players in helping to shape or even initiate positive change towards sustainable development. The general logic behind this view is that engineering knowledge is fundamental to any development process

[38] This finding corresponds with conclusions made by Case & Marshall (2015).

Figure 1: A capabilities-inspired framework for public-good engineering



and therefore their involvement in development efforts is central. However, the students also expressed doubts about the extent and reach of engineers' effective power as a professional group. This doubt is generally fuelled by the idea that engineers are not the ultimate decision makers in the corporate world, implying that engineers have limited voice and agency within industry, despite their pivotal knowledge that is used to advance 'development'. Students' views are that engineers' voices can best be heard within companies that explicitly address sustainable development challenges, or when engineers are in managerial positions in large companies. This shows that the students are able to recognise, discern, and articulate some of the economic and material constraints to engineers' professional freedom and agency; particularly in relation to advancing sustainable development through professional functionings.

According to Didier (2010), the highly compartmentalized work situation of engineers and the labour division which characterizes the large corporations in which they work creates a dilution of responsibilities and loss of orientation. This can result in an accepted 'blindness' for the actors involved (Didier, 2010). However, the work engineers do is attached with a moral obligation not to be ignorant, or worse indifferent, to the goals they are working to achieve (Didier, 2010). This is important because one cannot be held accountable for something about which one is ignorant (Didier, 2010). As discussed in the first chapter of this thesis, engineers have an ex-ante responsibility to contribute in solving sustainability challenges in a manner that is just. Thus conceived, engineers should neither lose sight of their objectives, nor be indifferent to social justice concerns.

Chapter 10

Summary, reflections and conclusion

10.1 Summary

Having outlined the background of this thesis and located engineering education in sustainable development, chapter 1 described the theoretical foundation for a normative account of engineering education. The chapter showed that for the purpose of this study, development was understood according to Amartya Sen's capability approach. I employed this approach as a normative framework to inform my understanding and conceptualisation of engineering education outcomes. I argued that the role of higher education institutions and universities in particular is not only to equip engineering graduates with job specific procedural knowledge, but also to aid in their own human development, which should result in them being able to achieve valued functionings that go beyond the technical aspects of their jobs.

I discussed how, through such education, engineering graduates should in turn be able to contribute to the well-being of others by designing, manufacturing and constructing social artefacts that improve capabilities for society, and in particular, the capabilities of poor and marginalised communities. I also discussed the concept of sustainable development and described how it can theoretically be enriched by the capability approach but also inform the approach's conceptualisation of development. Following this, I discussed sustainable human development as the ends of engineering education and provided justifications for my stance. The capability approach and human development paradigm proved to be useful in developing a normative critique of engineering education, and guided the research questions and objectives of the study. When looking at the education of engineers through the capability approach and human development paradigm, I was prompted to ask: What do future engineers value being and doing? How can engineering education enhance students' agency to achieve valued beings and doings?

These kinds of questions were helpful in directing my thinking about the focus of the study.

It was important for me to develop normative ideas about the kind of beings and doings engineers *ought* to value if they are to do the kind of work that explicitly contributes to social justice. Studies that incorporate the capability approach as a theoretical underpinning in their vision of higher education helped me conceptualise sets of opportunities, beings and doings that engineering graduates should value. To this end, work by Boni and Walker (2013), and Walker and McLean (2013), was influential for developing a capabilities-inspired, normative, theoretical vision of a professional 'public-good engineer', and work by Boni-AristÏzabal and Calabuig-Tormo (2015) helped generate ideas about what technical education might look like if it is to produce pro-poor, public-good engineers. The conceptualising of a set of capabilities and functionings focused on public-good engineering therefore provided a means of identifying what capabilities need to be enhanced through engineering education in order to produce engineers who care and commit to solving human problems like extreme poverty. This guided my theorizing of the kind of dispositions engineering graduates ought to have towards ideas of development and their own roles, if they are to enhance human flourishing by being public-good engineers.

Applying the capability approach as an evaluative lens to engineering education also served as a reminder not to over-prioritise performativity outcomes which are emphasised in skills discourses because doing so may lead to neglecting the transversal skills that are indispensable to public-good engineering (e.g. ethical learning, cosmopolitan abilities, critical thinking etc., discussed in chapter 3).

Chapter 2 described the sociohistorical context of higher education in Germany and South Africa in order to demarcate the space within which engineering education in universities can be understood. Looking at the relationship between universities and social transformation, it became clear that post-Apartheid South Africa and post-Nazi Germany had similar aspirations for higher education: to reform the university landscape and make it more inclusive so that members of society who had previously been excluded might have equal opportunities to participate in higher learning. This aspiration arose from the problem of differentiated higher education landscapes in the two countries. South Africa has had to deal with the legacies of Apartheid rule, and Germany, the effects of Nazi rule and a geographically and politically divided nation.

The chapter showed that in particular, student activism and protests have often served as catalysts for change; not only during periods of reconstruction, but also decades afterwards. For example, while the conditions prevailing at historically disadvantaged institutions in South Africa during the 1960s promoted the growth of student politicisation, the student movement that swept across Germany from 1966-1968 called for decision making in universities to be more transparent and to incorporate students' voices in policymaking, and for democratic freedom in all areas of society. More recently, Germany's free education movement that began in 1999 eventually resulted in the abolition of university tuition fees across the country in 2014. In South Africa, the year 2015 marked a reawakening of student protests over issues such as high student fees, exclusionary language policies, and calls for decolonising universities. In response to the #Fees Must Fall campaign, the South African government eventually declared that there would be no university fee increases in 2016.

In focusing on the relationship between universities and social transformation, chapter 2 showed that German and South African universities (like universities everywhere) take on multiple roles, serve diverse constituencies, respond to social unrest, and either challenge or reinforce established social patterns. Having discussed this relationship between universities and social change, the chapter also described significant differences and similarities of education and higher education across the two countries. In particular, education policy objectives, education structures, vocational training, number of universities and student populations, and university funding and governance were discussed. In conclusion, I argued that the biggest challenge for universities might be developing agentic engineers who are critical of unjust conditions in society and are able to (like student masses that have used their voices to effect changes in higher education in the past) use their agency to effect changes that they have reason to value.

The third chapter reviewed literatures on engineering education and started with a brief history of engineering and the education of engineers. Thereafter, I discussed contemporary examples of changes in engineering curricula, which are geared towards broadening engineering education outcomes. I discussed findings from international literature that dealt with various aspects of embedding soft skills and sustainability in engineering curricula and pedagogies. The common thread in this literature is the argument that engineering curricula and pedagogies should ensure that engineers do not "lose their human identity and abandon responsibility in influencing how the technology created by them is penetrating the lives of all people" (Jelen, 1997: 355). Other issues such as gender and engineering were discussed, which showed that being a woman, and being an engineer often represent two forms of being which can be difficult to integrate (Fuchs, 1997).

The literature review showed that measures to improve engineering graduates' soft and transversal skills or their dispositions towards sustainable development fall short of developing *all* students into agents of sustainable human development because many such courses are offered as elective subjects only. It also became clear that engineering education reform efforts appear fragmented and lack empirical evidence of their long-term effectiveness.

Chapter 4 began with a discussion of a capabilities lens on education in order to display its theoretical richness and demonstrate how it functions to conceptualize desirable changes that ought to take place in universities if they are to contribute more directly to social justice. Four essential dimensions of education were described in relation to their relevance for the development of public-good engineers. Following this, I described the process of developing ideal-theoretical lists of educational capabilities before presenting a normative framework for public-good engineering education, which draws from this process in its methodology. The chapter ended with an outline of this original framework that contributes innovatively to conceptualising public-good engineering education, going beyond Walker and McLean's (2013) more generalized framework.

In chapter 5, the data collection methods were described, along with issues of access to research participants, ethical clearance procedures, and the importance of ethical principles in research. When describing the data analysis procedure I focused on explaining how the interview transcripts were coded, what the intention of the analysis was and how I hoped to synthesize the findings. Chapter 5 thus concluded the first part of this thesis, which was dedicated to discussing the background, context, theoretical foundations of the study, and its methodology. The research process is reiterated below.

Table 17: Research summary

Big issue:	Engineering education for sustainable human development
Theoretical foundation:	Capability approach Human development paradigm Sustainable human development Public-good professionalism
Aim of the study:	To explore, describe and combine German and South African perspectives on engineering education in universities and its

	contribution to sustainable human development
Research questions:	How can the capability approach offer a normative critique of engineering education in universities? What capabilities and functionings are enlarged through engineering education? In addition, what implications do they have for pro-poor, public-good engineering? How can engineering education enable graduates, through their work, to function as agents of sustainable human development? How can engineering education also improve graduates' capability for employment?
Sources of empirical data:	Perspectives, opinions and insight from engineering employers (N=10), lecturers (N=10) and students (N=18)
Data collection methods:	Semi-structured interviews and focus groups discussions
Data analysis procedure:	Coding, conceptualizing, categorizing, theorizing

10.2 Reflecting on answers to the research questions

Research question 1: How can the capability approach offer a normative critique of engineering education?

This research question was primarily addressed in chapter 1, but also in chapter 4 (although later in the thesis, I drew on and integrated the empirical data to deepen the critique and application of the capability approach). While chapter 1 introduced the capability approach and broadly outlined its key concepts, chapter 4 elaborated more specifically on the capability approach and higher education research.

Chapter 1 explained why it is problematic to consider all engineering outcomes as examples of development. This was done through a discussion that highlighted how unrestrained advancement of infrastructure and technology have become questionable due to the adverse effects suffered by the environment and doubts about the extent to which this will lead to positive change for society in the long run. Having discussed the resultant rise in prominence of sustainability as an alternative, more expansive framework for understanding human progress, the chapter asked how development itself might be better understood. I argued that when thinking of development in the traditional utilitarian sense, it is easy (and appropriate) to evaluate the work engineers do as a contribution to human flourishing (because transforming natural resources into means of production for industrialization and expanding infrastructure or advancing technology are all examples of engineering outcomes that boost economic development). I then pointed out that when we think of development from a human development, instead of a human capital perspective, we are prompted to pay more attention to non-economic dimensions of well-being.

The capability approach, with its conception of development as the effective freedoms and opportunities (capabilities) available to people to strive for and achieve valued 'beings' and 'doings' (functionings), offers the starting point of the human development paradigm, which defines the goals of development as the expansion of people's capabilities and functionings.

As Boni and Walker (2013) posit, a human development perspective provides a good framework to rethink and reimagine a different vision of the university, beyond the goal to prepare people as a workforce. Looking at development from a capabilities perspective and adopting the human development paradigm's normative account on development has specific implications for defining engineering outcomes: if engineering outcomes are to contribute to development, they should expand valuable capabilities and functions for *all* people. Similarly, if engineering education is to contribute to students' development, it ought to enhance their valued capabilities and functionings.

In this way, the capability approach offers a foundation for normative descriptions of processes that aim to result in development. Examples of such processes include engineering education, because it produces a workforce of professional engineers who often work at the forefront of development. At the same time, descriptions of what engineering education ought to do, are also helpful in identifying what it ought *not* to do, thereby providing grounds for criticism. Following this line of thinking, I described engineering education for sustainable human development as:

> Education that enlarges the professional capabilities of engineering graduates, whilst providing them with opportunities to develop, demonstrate and deepen their commitment to causes such as poverty eradication, and at the same time enhances their ability to exercise their agency to promote sustainable human development through their work.

Drawing from this definition, the following can be said about engineering education:

> Engineering education that does not provide students with opportunities to engage meaningfully with knowledge about poverty, and sustainability, falls short of its contribution to sustainable human development.

In this way, the capability approach aptly provides a framework for normative critiques of engineering education. More specifically, the capability approach can be used as a theoretical basis to help broadly describe what the outcomes of engineering education should be, if future engineers are to advance sustainable human development through their work.

Research question 2: What capabilities and functions are enlarged through engineering education? In addition, what implications do they have for pro-poor, public-good engineering?

The second research question was addressed in chapters 6, 7 and 8. Identifying capabilities and functionings that are enlarged through engineering education was an iterative process that required going back and forth between data and theory i.e. describing what emerged from the analysis of the findings, reflecting on how the findings relate to the ideal-theoretical, capabilities-inspired normative account of engineering education, and then referring back to the data. In brief, I identified students' valued functionings from the data, and then shortened this list according to the beings and doings that are theoretically most relevant for what I described as public-good engineering in chapter 1. Thereafter, I compared the shortened list of functionings to the dimensions of public-good engineering as identified in the findings from employers' perspectives (chapter 6), before distilling the list of again. Finally, I extrapolated the corresponding capabilities that are necessary for the achievement of the identified functionings (summed up below).

Table 18: Educational capabilities and functionings for public-good engineering

Capabilities	Functionings

Solving problems	Applying engineering knowledge to help solve problems and challenges associated with sustainable human development.
Being confident and feeling empowered	Developing one's sense of confidence and exercising individual and collective agency to advance social justice.
Being resilient and having a sense of affiliation	Developing a sense of belonging with fellow engineers and learning to persevere in the face of individual failure.
Working in diverse fields	Being employable and having opportunities to apply professional engineering expertise in a wide range of contexts, industries, and job positions for the sake of the public good.

Having identified these capabilities and functionings, the first part of research question 2 was answered. Building on these results, I then addressed the second part of the question, drawing from the results presented in chapter 6 (employers' perspectives) and chapter 7 (lecturers' perspectives). To recap, public-good engineering was defined as engineering that:

- is founded on principals of *homo reciprocans* rather than *homo economicus*;
- seeks to expand capabilities and enable valued functionings for (poor) communities;
- meaningfully engages with such communities, where possible, to ensure that engineering accomplishments will benefit them in ways that they have reason to value in the long run; and
- is not carried out with disregard to the environment and acknowledges the boundaries of human influence on it.

Non-technical skills conducive to this type of engineering are:

Critical thinking and open-mindedness, along with communication and collaboration.

The goals of engineering education were described as seeking to:

- Develop students' capacities to exercise agency, make decisions autonomously and create innovative approaches and methods to solution seeking founded on engineering knowledge;
- Enhance students' sense of determination to be and do what they have reason to value in life as well as determine their roles in society;
- Stimulate students' desire for knowledge and help them recognise opportunities where they can successfully apply what they learn to their work and in their lives;
- Provide students with opportunities for research-based learning;
- Provide students with the necessary knowledge and skills that they need to become engineers and be employable; and
- Develop students' potential to take responsibility for running engineering companies and be accountable for the engineering outcomes produced by them.

Mapping out the functionings, dimensions of public-good engineering, non-technical skills associated with it, and the goals of engineering education, I theorised the potential links between the main findings across the empirical chapters. This was done in order to generate a capabilities-inspired, empirically informed framework for public-good engineering education (see diagram 1). This framework represents a descriptive and normative account of the significance of capabilities and functionings enlarged through engineering education, for pro-poor, public good-professionalism. It also illustrates what engineering education might look like, if it is to enhance future engineers' opportunities to use their agency to practice public-good engineering for human development.

To summarise the answer to research question 2: Engineering education in universities can enlarge a wide range of valued capabilities and functionings that have different degrees of relevance for public-good engineering and hence, sustainable human development. However, it does not always do so. A new normative underpinning developed in this study is therefore advanced.

Research question 3: How can engineering education in universities enable graduates (through their work) to function as agents for sustainable human development and social justice?

This question was addressed across chapters 1, 6, 7, 8 and 9. In chapter 1, I defined sustainable human development, put forward arguments for why it should be considered as the overarching outcome of engineering education and provided normative accounts of engineering education for sustainable human development. In different ways, chapters 6, 7 and 8 contributed parts of the answer. Chapter 6 defined public-good engineering (based on empirical data), which in itself is an aid to sustainable human development (because of its goal to expand valuable capabilities and functioninigs for (poor) communities and ensure that engineering outcomes benefit them in the long run). Chapter 7 described lecturers' views on curricula and pedagogies that are helpful in developing students' non-technical skills, while chapter 8 reflected on what students learn from sustainability and non-technical courses. The biggest part of the answer was contained in chapter 9, which discussed the reach of engineering education in teaching values associated with sustainable development and students' perceptions of their potential to advance it. It highlighted students' critical reflections on engineering for sustainable development and indicated that they understand 'sustainable development' as a fluid concept. The chapter also showed that students have ambitions to initiate positive change in society through their work, but that they doubt the effective power of engineers to be drivers of this change. This doubt is fuelled by concerns that *homo economicus* principles govern industry to the extent that profit maximisation is prioritised at the expense of sustainable engineering.

Additionally, students do not think that engineers are influential enough to help reprioritise the goals of the companies they might work in towards sustainable development. As such, the findings suggest that engineering education enhances students' sense of empowerment, confidence, and personal development, but it does not necessarily enhance their individual agency to forge pathways in the engineering industry to advance sustainable development. Through this discussion, this chapter therefore highlighted issues of structure and agency. It showed, through original empirical research asking new questions of engineering education, that if universities do not develop agentic public-good engineers, engineering outcomes might reinforce social inequality by primarily serving the capabilities of those who are already well off, as opposed to enhancing the capabilities of impoverished communities.

In brief, engineering education in universities can enable graduates to function as agents for sustainable human development by harnessing their agency. More specifically, engineering education in universities should develop and strengthen graduates' potential to exercise agency so that they are able to initiate and create engineering solutions that are consistent with social justice values whilst they navigate personal, environmental, and social conversion factors or constraints, and cope with the contradictions they are likely to encounter when they enter the workplace.

Research question 4: How can engineering education also improve graduates' capability for employment?

The answer to the final research question was addressed in chapter 6. Employers' views on the ideal engineer reflect a range of technical and non-technical skills they would like graduate engineers to possess. These skills reflect attributes that the employers consider valuable in industry. Based on my interpretation of their views, engineering education can improve graduates' capability for employment if it enables them to:

- Have a broad view of the engineering profession;
- Recognise the diverse contexts in which technical knowledge can be applied;
- Understand the interconnectivity between technical solutions and human problems;
- Translate theory into practice both in the office space and on project sites;
- Think critically and exercise open-mindedness; and
- Communicate and collaborate effectively.

Based on the empirical data which was used to answer the four research questions (chapters 6 to 9), and building on the theoretical foundations laid out in chapters 1 and 4, engineering education that is most likely to support the development of public-good professional engineering functionings was illustrated in the framework summarised in diagram 1 (see page 222).

10.3 Original contribution

The study makes an original conceptual and empirical contribution to how we can think differently about engineering education in both global South and global North contexts; the combined conceptual and empirical application is important. On its own, rich qualitative empirical data on engineering education in universities tells us much about the aspirations, experiences, and opinions of engineering students, lecturers, and employers. This is important because it provides the evidence needed from which we can then build our understanding of engineering education phenomena. However, using the capability approach as both a normative lens for theorizing, and a site for analysing this data, enriches the value of the data because it provides valuable conceptual grounds for critically assessing, and problematizing what is going on in engineering education in universities.

This thesis showed how the capability approach could be informed by the concept of sustainable development to result in a view of human flourishing as 'sustainable human development'. It also showed that much work has been done to promote infusing the concept of sustainable development into engineering education. However, there are no studies that explicitly describe the normative objectives of engineering education according to a capabilities-inspired conceptualisation of sustainable human development. That is, although there are global action plans and institutional responses to 'Education for Sustainable Development' or ESD, and 'Engineering Education for Sustainable Development', similar efforts have not been done to advance what I refer to as 'Engineering Education for *Sustainable Human Development*' or EESHD. This is an original theoretical contribution to engineering education literature.

Combined perspectives (in this case from the global North and South) are more than the sum of individual views; they provide a new window through which to perceive the value of engineering education. In the same way that the colour green results from mixing blue and yellow, combining German and South African perspectives creates a new outlook, which allows us to see some 'blind spots' that may otherwise not have been achieved had the perspectives merely been *compared* to one another. Thus conceived, this thesis advances a critique of comparative engineering education research, opting instead to showcase the importance of recognising the synergy created from combining global North and global South perspectives on engineering education.

10.4 Limitations of the study

Notwithstanding that the study enables a fresh and innovative look at engineering education, the qualitative nature of this study means that the findings are not generalizable to broader populations. The study also contains data that was collected from two universities that were specifically selected because of their explicit commitment to addressing sustainable development in their engineering curricula. Therefore, the findings from the University of Cape Town and Universität Bremen arguably reflect 'best case' examples of engineering education in global South and global North countries respectively. They do not reflect what students and lecturers at more conventional universities might perceive of engineering education. Nonetheless, the findings point to possibilities but also to challenges that can resonate in other contexts and other universities.

Although the literature review identified a scarcity of engineering education literature that draws on longitudinal qualitative data, time constraints limited the possibility for this thesis to provide such data. Another limitation is that gender is touched on in this thesis, but not fully explored. The same applies to other identity issues such as race, culture, and nationality. Finally, other theoretical approaches that can contribute to conceptualisations of public-good engineering education were not fully examined. To this end, an explicit focus on 'engineering for social justice' advanced by scholars such as Cumming-Potvin and Currie (2013) and research advancing principles of universal design in engineering (see Bailey, 2009; Nieusma, 2004; Nieusma & Riley, 2010; Oosterlaken, 2009; Petersen, 2013) can enrich our thinking about EESHD. Although these ideas are touched on in this thesis, their significance for theorizing EESHD was not explored exhaustively.

The identified limitations are, however, also avenues for future research.

10.5 Future directions in research

It would be interesting to track and monitor the engineering students interviewed for this study, as they progress into industry. Longitudinal data on their working experiences which looks at the kind of companies they go into, the type of work they do and their current perception of individual agency would be the key aspects to look at. Doing so would provide empirical data that can be used to tell us how well or to what extent the graduates are able to function as agents of sustainable human development. Moreover, it is important to find opportunities to test the framework of public-good engineering against practices and with a wider audience. As such, future research might seek to answer questions such as:

> How robust and convincing is the list of public-good engineering capabilities developed theoretically and empirically in this study?
>
> AND/OR
>
> How robust is the framework for public-good engineering education developed in this study? In addition, how can it be translated into practice?

Finally, research (in South Africa in particular) that attends to how becoming and being a public-good engineer is shaped by student biographies of gender, race but also social class, is much needed to inform both educational and social justice policy, practices, and outcomes.

10.6 Public engagement

This study is also concerned to engage an audience in discussion about public-good engineering beyond the academy, given the influences of employers, colleagues and the work context not only on the engineering curriculum, but also on practices post-university. To this end, this process was initiated by presenting a paper in July 2015 titled, "We think we're helping, but are we really?: Critical reflections on engineering for sustainable development". The audience for this presentation was a group of members of the German Association of Engineers. 14 senior German engineers, who have been living and working in South Africa for an average of 20 years made up the audience at the meeting (one of whom I had interviewed for my study). Amongst them, only one female engineer attended (highlighting again the need for further research that attends to gender).

I used this meeting as an opportunity to validate my interpretation of the data and find out what a broader group of practising engineers thought about some of the conclusions drawn from the data. I recorded the discussion that ensued after my presentation. The discussion was not analysed with the same rigour applied to the primary data of this thesis, due to time constraints. However, the following summary can be made from the discussion, based on a tentative thematic analysis and memo writing:

The VDI (German Association of Engineers) members generally have similar ideas about the concept of sustainable development that were presented in chapter 8. They see sustainability as a vague concept and worry that it is used too loosely and frequently. The audience also place an emphasis on the structural constraints that get in the way of engineering which is conducive to social justice. The South African political climate was described as one that does not adequately allow this. They spoke about the opportunities and possibilities for more sustainable engineering projects that could be implemented in South Africa (especially in response to the energy crisis) but cited corruption and cumbersome red tape as the biggest constraints for this to happen. They also echoed the sentiment that, too often, non-engineers make the final decisions about the engineering projects that are implemented. Some points were made about the importance of incremental changes in this regard; that sometimes the only way to change something is by doing 'a little bit at a time'.

The VDI members appreciated having a non-engineer present at their meeting and said the discussion allowed them to step back from the typical, technical engineering content that is usually talked about at their monthly meetings. Doing so, they said, gave them an opportunity to think about their work more broadly than they allow themselves to do on a daily basis. This is an important point because it shows that the results of this thesis have potential significance for engineering professionals, because it prompts critical reflection about the purpose and value professional engineering functionings. It also implies that my non-engineer researcher positionality was appreciated by the audience, and hence that it was beneficial to the research.

I also presented papers to local and international audiences at academic and practitioner conferences. In 2013, I presented a conference paper at the Higher Education Learning and Teaching Association of Southern Africa held in Pretoria. In 2014 and 2015, I presented at the annual conferences of the Human Development and Capability Association held in Athens and Washington DC; and in 2015 at the Conference 'On Innovation for Sustainability under Climate Change and Green Growth', held in Johannesburg.

Sharing the findings of my study is important not only to receive feedback from my peers, but also for the sake of participatory dialogue, which is strongly emphasized by Sen (2009) as integral to the process of agreeing on which capabilities ought to be prioritised and developed. Making the results of this study public at conferences and seminars and engaging with diverse scholarly audiences is thus part of the process of defending my framework for public-good engineering education and inviting other voices to critically review it. This process can contribute to the refinement of the framework and a more robust list of educational capabilities for public-good engineering. Public engagement also creates avenues for thinking about teaching and learning in engineering education, and for 'speaking' to policy and policy-makers.

10.6 Concluding remarks

Although technical excellence is a fundamental attribute of engineering graduates, critical thinking, open-mindedness, effective communication and collaboration, and a valuing of their public good contributions are also crucial. Developing students' confidence, resilience and agency is equally important if this to happen. Neglecting development in these areas is not in the best interest of producing sensible and compassionate public-good engineers who can exercise their agency in industry to promote sustainable human development.

In the same way that this thesis speaks to some of the central questions about development and engineering outcomes from a capabilities perspective, it also approaches the question of the relationship between universities and the public good from a human development viewpoint. As the discussion of public-good professionalism has shown, a capabilities lens on engineering professionalism points to multidimensional freedoms and functionings-particularly those of the poor - as proxies of development that is just.

The process of carrying out this study resulted in my desire to see engineering defined and practiced differently so that engineers can work in a variety of contexts from and on behalf of social justice values, rather than against them. It is clear that the engineering students want their work to matter outside of corporate or profit driven contexts, yet some of them struggle with their commitments to traditional engineering values associated with objective 'problem-solving'. Work on engineering education for sustainable human development should continue to explore these tensions, and discover how they might be overcome so that future engineering endeavours might contribute more ardently towards eradicating poverty.

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Appendices

Appendix A: Information page for research participants

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

Centre for Higher Education and Capabilities Research (CHECaR)

__Information page for research participants__

PhD working title
Engineering Education in Universities and its Contribution to Sustainable Human Development in Germany and South Africa

Abstract
Traditional talk about job related technical skills and competences as the sole outcome of university learning is dated. This view of education, as the means with which graduates are prepared to enter the job market, fuels common skills-talk in employability discourses which rightfully emphasizes the economic utility of education yet neglects considerations about the intrinsic motivation and value of learning for individuals, and the significance thereof for individual and societal well-being. With regard to the education of engineers in particular, several studies support the notion that outcomes should include a heightened awareness of the potential consequences of engineering activities on what have been described as the three pillars of sustainable development (society, the economy, and the environment). These outcomes can result through a cultivation of transversal skills that aid critical reflexive consideration of the extent to which technological advancements achieved through various engineering activities truly contribute to the well-being of society. Using the capability approach as a normative framework to define the broader contribution higher education should make to sustainable human development; this study seeks to explore, describe and juxtapose engineering education outcomes in Germany and South Africa. An interpretivist paradigm underlies this study and qualitative methods of inquiry are employed to collect data at one university in each country. Findings will promote discussions on developing professional engineers who are positive social change agents enabled through their education to contribute to the capability expansion and well-being of society. The findings could also shed light on some global concerns related to engineering education, engineering practice and development issues in Germany and South Africa.

Key words: Engineering education, capabilities approach, sustainable human development, Germany, South Africa

Purpose of research
The interviews I intend to conduct with industry representatives will aid my interrogation of the importance and relevance of transversal skills in engineering education for engineering practice. As representatives from the engineering industry across several companies in Germany and South Africa, I intend to gain perspectives, opinions, and thoughts on what attributes (aside from technical excellence) are desirable for engineers in a modern world.
The interviews with university staff are aimed at gaining perspectives from the respective engineering departments at the selected universities on their perception of teaching and learning in engineering, the value of engineering education, as well as their views on its relation to sustainable development. The focus group discussions with students are geared towards gathering students' voices on their university learning experiences and what they value about engineering education.

Your participation will be greatly appreciated.
Mikateko Höppener,

PhD Fellow (CHECaR, UFS)

For more information, queries or questions please e-mail me at: hoeppenerm@gmail.com, call me on: +27 79 555 1131 or go to: http://checar.ufs.ac.za/content.aspx?uid=6

Appendix B: Informed consent form

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS UV

Centre for Research on Higher Education and Development (CRHED)

<u>Informed consent form for participation in the study</u>

I……………………………………..……………………………………………………..
(Participant's first name and last name)

agree to participate in Mikateko Höppener's research study. The purpose and nature of the study has been explained to me in writing per e-mail and I have read the '*Information page for research participants*'.

I am participating voluntarily and give permission for my interview to be tape-recorded and I understand that I can withdraw from the study, without repercussions at any time.

I also understand that anonymity will be ensured in the write-up by disguising my identity and agree that extracts from my interview/focus group discussion may be quoted in the thesis and any subsequent publications.

………………………………… Signature

……………………………………….............. Place, Date

Researcher: Mikateko Höppener

PhD student (CRHED, UFS)

For more information, queries or questions please e-mail me at: hoeppenerm@gmail.com, call me on: +27 79 555 1131 or go to: http://checar.ufs.ac.za/content.aspx?uid=6

Appendix C: Ethical clearance approval letters

Faculty of Education
Ethics Office

Room 12
Winkie Direko Building
Faculty of Education
University of the Free State
P.O. Box 339
Bloemfontein 9300
South Africa

T: +27(0)51 401 9922
F: +27(0)51 401 2010

www.ufs.ac.za
BarclayA@ufs.ac.za

27 May 2014

ETHICAL CLEARANCE APPLICATION:

PERSPECTIVES ON ENGINEERING EDUCATION IN UNIVERSITIES AND ITS CONTRIBUTION TO SUSTAINABLE HUMAN DEVELOPMENT IN GERMANY AND SOUTH AFRICA

Dear Ms Hoppener

With reference to your application for ethical clearance with the Faculty of Education, I am pleased to inform you on behalf of the Ethics Board of the faculty that you have been granted ethical clearance for your research with the following stipulation (comments by reviewers):

- It is advisable that you do not request the email addresses directly from the institutions, as they are not permitted to distribute email lists or other personal data to third parties. Request, in your permission letter, that they distribute the informed consent letter on your behalf by email to their students/staff, requesting these to email you directly should they be willing to participate in your research.

Your ethical clearance number, to be used in all correspondence, is:

UFS-EDU-2014-022

This ethical clearance number is valid for research conducted for one year from issuance. Should you require more time to complete this research, please apply for an extension in writing.

We request that any changes that may take place during the course of your research project be submitted in writing to the ethics office to ensure we are kept up to date with your progress and any ethical implications that may arise.

Thank you for submitting this proposal for ethical clearance and we wish you every success with your research.

Yours sincerely,

Andrew Barclay
Faculty Ethics Officer

CENTRE FOR HIGHER EDUCATION DEVELOPMENT
UNIVERSITY OF CAPE TOWN

PD Hahn Building, North Lane, Upper Campus
Postal Address: Private Bag Rondebosch 7701
Telephone: (021) 650-5027
Fax No.: 650-5045

8 June 2014

Ms Mikateko Höppener
PhD student
Centre for Research on Higher Education and Development
University of the Free State

Dear Ms Höppener

Re: Perspectives on engineering education in universities and its contribution to sustainable human development in Germany and South Africa

The Research Ethics Committee of the Centre for Higher Education Development has reviewed the documentation you submitted to it in respect of the above proposed PhD research project.

I am very pleased to confirm that the REC has approved the research to proceed at the University of Cape Town on the terms specified in your submissions to the Committee. Should the research focus and process change in any substantive way, you are requested to make a new submission to the Committee.

We wish you all the best with the work.

Yours sincerely

Alan Cliff
Chair, CHED REC
(on behalf of the Committee)

"Our Mission is to be an outstanding teaching and research university, educating for life and addressing the challenges facing our society."

EBE Faculty: Assessment of Ethics in Research Projects (Rev2)

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).
NB: A copy of this signed form must be included with the thesis/dissertation/report when it is submitted for examination

This form must only be completed once the most recent revision EBE EiR Handbook has been read.

Name of Principal Researcher/Student: Mikateko Höppener Department: Centre for Development Support, University of the Free State

Preferred email address of the applicant: hoeppenerm@gmail.com

If a Student: Degree: PhD Supervisor: Prof. Melanie Walker

If a Research Contract indicate source of funding/sponsorship: N/A

Research Project Title: **Perspectives on engineering education in universities and its contribution to sustainable human development in Germany and South Africa**

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**
Question 2: Is your research making use of human subjects as sources of data? If your answer is YES, please complete Addendum 2.	**YES**	NO
Question 3: Does your research involve the participation of or provision of services to communities? If your answer is YES, please complete Addendum 3.	YES	**NO**
Question 4: If your research is sponsored, is there any potential for conflicts of interest? If your answer is YES, please complete Addendum 4.	YES	**NO**

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. Ensure that you refer to the EiR Handbook to assist you in completing the documentation requirements for this form.

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 constitute plagiarism.

Signed by:

	Full name and signature	Date
Principal Researcher/Student:	Mikateko Höppener	11.04.2014

This application is approved by:

Supervisor (if applicable):	Prof. Melanie Walker	11.04.2014
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.	[signature]	30/5/2014

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

NB. Please double click to open document.

Perspectives on engineering education in universities and its contribution to sustainable human development in Germany and South Africa

Proposal

Mikateko Höppener

PhD student, Centre for Research on Higher Education and Development

Supervisor: Prof. Melanie Walker

Co-supervisor: Dr. Merridy Wilson-Strydom

University of the Free State

04 November 2013

HR194	ACCESS TO UCT STAFF FOR RESEARCH PURPOSES	UNIVERSITY OF CAPE TOWN IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

NOTES

- Forms must be downloaded from the UCT website: http://www.uct.ac.za/depts/sapweb/forms/forms.htm
- This form must be completed by applicants who are requesting to access UCT staff for the purpose of research.
- A copy of the research proposal as well as the Ethics Committee approval must be attached.
- It is the **responsibility of the researcher/s to apply for ethical clearance** from the relevant Faculty's Research in Ethics Committee (REC).
- If you are requesting staff information, you are required to complete the HR Information Request Form (HR190) and submit it together with all the required documentation.
- The turnaround time for a reply is **approximately 10 working days unless specified as urgent.**
- Return the completed application form and all the above documentation to Joy Henry via email: joy.henry@uct.ac.za or deliver to: For the Attention: Executive Director, Human Resources Department, Bremner Building, Room 214, Lower Campus, UCT.

SECTION A: APPLICANT DETAILS

Title	Mrs	Name	Mikateko Höppener
Telephone number	+27(0) 79 555 1131	Email address	hoeppenerm@gmail.com
Student number	2004119232	Staff number	N/A
Visiting researcher ID / passport number	8511250272083		
Faculty Officer contact details	Willem Ellis		
	Email: EllisWF@ufs.ac.za Tel.: +27(0)51 401 3775		
University or institution at which employed or a registered student	University of the Free State		
Faculty or department in which you are registered or work	Centre for Development Support		
Address (if not UCT)	205 Nelson MAndela Drive		
	Parkwest, Bloemfontein		
	9301		

SECTION B: SUPERVISOR DETAILS

	Title and name	Telephone number	Email address
Supervisor	Prof. Melanie Walker	+27 (0)784348820	walkermj@ufs.ac.za
Co-Supervisor	Dr. Merridy Wilson-Strydom	+27(0)51 4017566	wilsonstrydommg@ufs.ac.za

SECTION C: APPLICANT'S FIELD OF STUDY (if applicable) / TITLE OF RESEARCH PROJECT / STUDY

Degree	PhD in Development Studies	
Research project or title	Perspectives on engineering education in universities and its contribution to sustainable human development in Germany and South Africa	
Research proposal attached	☒ Yes	☐ No
Target population (number of UCT staff)	2	
Amount of time required for an interview and/or questionnaire	1 hour	
Lead Researcher details	Mikateko Höppener (same as applicant)	
Proof of ethical clearance status attached	☒ Yes	☒ No

SECTION D: FOR OFFICE USE (Approval status to be completed by the Executive Director, Human Resources or Nominee)

Support or approval			Role	Signature	Date
Supported?	☒ Yes	☐ No	Joy Henry (Office Co-Ordinator)	[signature]	11/06/14
Approved?	☒ Yes	☐ No	Miriam Hoosain (Executive Director: HR)	[signature]	11/06/14

RECEIVED
11 JUN 2014
ED: HR OFFICE

	RESEARCH ACCESS TO STUDENTS	DSA 100

NOTES

1. This form must be **FULLY** completed by all applicants that want to access UCT students for the purpose of research.
2. Return the fully completed **(a) DSA 100** application form **by email**, in **the same word format**, together with **your: (b) research proposal inclusive of your survey, (c) copy of your ethics approval letter / proof (d) informed consent letter** to: Moonira.Khan@uct.ac.za. You application will be attended to by the Executive Director, Department of Student Affairs (DSA), UCT.
3. The turnaround time for a reply is **approximately 10 working days.**
4. NB: It is the responsibility of the researcher/s to apply for and to obtain **ethics approval and to comply with amendments that may be requested;** as well as **to obtain** approval to access UCT staff and/or UCT students, from the following, at UCT, respectively: (a) **Ethics:** Chairperson, Faculty Research Ethics Committee' (FREC) for ethics approval, (b) **Staff access:** Executive Director: HR for approval to access UCT staff, and (c) **Student access:** Executive Director: Student Affairs for approval to access UCT students.
5. **Note:** UCT Senate Research Protocols requires compliance to the above, **even if prior approval has been obtained from any other institution/agency. UCT's research protocol requirements applies to *all* persons, institutions and agencies from UCT and external to UCT who want to conduct research on human subjects for academic, marketing or service related reasons at UCT.**
6. **Should approval be granted to access UCT students for this research study, such approval is effective for a period of one year from the date of approval (as stated in Section D of this form), and the approval expires automatically on the last day.**
7. **The approving authority reserves the right to revoke an approval based on reasonable grounds and/or new information.**

SECTION A: RESEARCH APPLICANT/S DETAILS

Position	Staff / Student No	Title and Name	Contact Details (Email / Cell / land line)
A.1 Student Number	2004119232	Mrs Mikateko Höppener	hoeppenerm@gmail.com +27 (0)79 555 1131
A.2 Academic / PASS Staff No.			
A.3 Visitor/ Researcher ID No.	8511250272083		
A.4 University at which a student or employee	University of the Free State	Address if *not* UCT: 205 Nelson Mandela Drive, Bloemfontein, 9301	
A.5 Faculty/ Department/School	Centre for Research on Higher Education and Development/ Centre for Development Support		
A.6 APPLICANTS DETAILS If different from above	Title and Name	Tel.	Email

SECTION B: RESEARCHER/S SUPERVISOR/S DETAILS

Position	Title and Name	Tel.	Email
B.1 Supervisor	Prof. Melanie Walker	+27 (0)76 4348820	walkermj@ufs.ac.za
B.2 Co-Supervisor/s	Dr. Merridy Wilson-Strydom	+27 (0)51 401 7566	wilsonstrydommg@ufs.ac.za

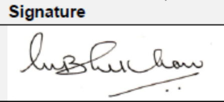
SECTION C: APPLICANT'S RESEARCH STUDY FIELD AND APPROVAL STATUS

C.1 Degree – if applicable	PhD in Development Studies
C.2 Research Project Title	Perspectives on engineering education in universities and its contribution to sustainable human development in Germany and South Africa
C.3 Research Proposal	Attached: Yes [X] No [ ]
C.4 Target population	6 to 12 MSc. Or MEng students in any engineering discipline
C.5 Lead Researcher details	If different from applicant:
C6. Will use research assistant/s	Yes [ ] No [X] If yes- provide a list of names, contact details and ID no.
C.7 Research Methodology and Informed consent:	**Research methodology**: Focus group discussions. **Informed consent:** Written informed consent letter to be e-mailed to selected students to read and sign ahead of any collection of data
C.8 Ethics clearance status from UCT's Faculty Ethics Research Committee (FREC)	Approved by the FREC Yes [X] With amendments: Yes [ ] No [redacted] (a) Attach copy of your ethics approval. Attached: Yes [redacted] (b) State date and reference no. of ethics approval: Date: 8 June 2014 Ref. CHED FREC

SECTION D: APPLICANT/S APPROVAL STATUS FOR ACCESS TO STUDENTS FOR RESEARCH PURPOSE

(To be completed by the ED, DSA or Nominee)

	Approved / With Terms / Not	* Conditional approval with terms	Applicant/s Ref. No.:
D.1 APPROVAL STATUS	(i) Yes [redacted] ~~(ii) With terms~~ ~~(iii) No~~	(a) Access to students for this research study must only be undertaken after written ethics approval has been obtained. (b) In event any ethics conditions are attached, these must be complied with before access to students.	UFS/2004119232/ Mrs Mikateko Höppener

	Designation	Name	Signature	Date of Approval
D.2 APPROVED BY:	*Executive Director Department of Student Affairs*	*Dr Moonira Khan*		*18 June 2014*

Appendix D: Employer interview guide

Interview guide for group 1: Industry representatives (N=8-10)

Purpose of interviews: to interrogate the importance and relevance of transversal skills for engineering practice, from employers' perspectives

Section 1: Engineering graduate attributes

1. How would you describe the ideal/perfect engineer?
2. What skills and competences are most important in the engineering profession?
3. What are your expectations of engineering graduates?
4. To what extent do engineering graduates live up to these expectations?
5. What is the most important aspect of knowledge formation in engineering education?

Section 2: Perceptions of transversal skills

1. How important are 'soft skills'/'transversal skills' in the engineering profession?
2. Could you give some examples of soft skills you would like to see engineers practice?
3. What is your opinion concerning the relevance of the following soft skills for engineering practice:
    - Critical thinking?
    - Ethical learning?
    - Intercultural communication?
    - Team work?
    - Cosmopolitan abilities?
4. How do engineering activities affect societal development?
5. What role do engineers play with regards to sustainable development?

Section 3: Engineering education and advice to engineering educators

1. What are the most significant technical skills in the knowledge base of engineers?
2. How important is this in relation to transversal skills?
3. How can higher education institutions best prepare engineering students for the workplace? How can higher education institutions best develop soft/transversal skills?
4. What is the relevance – if any- of humanistic subjects in engineering education?
5. Is there anything else you would like to add on this topic?

Appendix E: Lecturer interview guide

Interview guide group 2_university lecturers (N=8-10)

The purpose of the expert interviews with academic staff is to gather perspectives on engineering education from individuals who have extensive experience in teaching and learning

Questions:

1. How would you describe the purposes of engineering education in universities?

2. What skills and competences are central to engineering education outcomes?

3. What non-technical skills and competences are central to engineering education outcomes?

4. How important are “soft skills”/”transversal skills” in engineering practice? And what measures is the department taking to emphasize the necessity and importance thereof?

5. Could you give some examples of soft/transversal skills that are fostered/ promoted in the courses you teach/have taught?

6. What pedagogical practices are employed to promote critical thinking?

7. Do you feel that engineering graduates understand the complexity and interconnection of megatrends influenced by consequences of innovation and development efforts related to engineering activities?

8. How does the engineering curriculum in this university address sustainable development concerns? Or what examples come to mind of initiatives, courses or modules that particularly focus on addressing sustainable development issues?

9. How would you describe the link between universities, engineers and sustainable development?

10. What do you think of the following statement?

“Education institutions should also promote social goods, through enhancing: personal development, contributions to society, fair participation in the economy, well-being, participation and empowerment, equity and diversity, sustainability, world citizenship, imaginative understanding and freedom”.

Appendix F: Student focus group discussion guide

Focus group schedule for group 3: MSc/MEng students. N=8 -12

Two focus groups, each with 4-6 participants. The purpose of the focus group discussions with masters students is to gather perspectives on personal experiences in engineering education in relation to the following topics:

Section 1: Intrinsic motivation for studying engineering

1. Let's talk about your motivation to study engineering: why did you choose to study engineering?
2. What do you value most about what you have learned through your engineering studies?
3. What do you think your roles as future engineers are in society?

Section 2: Perception and experience of transversal skills in engineering education

4. How important do you think "soft" or transversal skills are in the engineering profession? Could you give some examples?
5. To what extent do you feel you are gaining such skills in your current studies? Could you give some examples?

Section 3: Perception of sustainability concerns in engineering education

6. What do you understand under the term "sustainability"
7. What role do you think engineers play with regard to sustainable development?
8. What moral or ethical responsibilities do you think engineers have towards society in this regard?

Section 4: Capability expansion through engineering education

9. Where do you see yourselves in five years' time? OR could you describe what you hope to achieve in the near future: in terms of your career? The kind of life you would like to live? The kind of personal and professional aspirations you would like to achieve?
10. How-if at all- do you think your studies enable you reach these ambition

Appendix G: Sample transcript

Interview transcript: 17
Interviewer: Mikateko Höppener (MH)
Interviewee pseudonym: Maria Schwartz (MS)
Date: 22.05.2014
Place: Bremen University, interviewee's office
Duration: 40 minutes
Remarks: Interview conducted in English

MH: What are the goals of engineering education? What should be the outcomes of engineering education be when students graduate from university?

MS: Engineering students when they leave university with a masters degree and I stress masters degree because for me that's the final degree for an engineering student; bachelor for me is intermediate. It's not the final degree from my personal perspective. Independent from what is political. But due to the deep technological technical knowledge we need- and also due to the times that we need to give the students the experience to be able to handle complex situations- we need the five years; to really get them done. Coming back to the question-what should they know- they should have gathered a broad knowledge, they should build- I used to take the picture of Indiana Jones, you know the movie?

MH: Yes

MS: When he is in the temple in Petra, then he has all the piles and some of them break down and some of them are stable- all of our students have to go during their career, through such a field and you never know in advance which way is the right one for each of them. And what we're doing in the student time is that we build up these tiles so that we give them the opportunity to build up on them, to build new houses on these tiles. And to be able to decide which piles to use and to be able to make up new things from the common ground. To build up new things, new ideas, new products, new processes from what they know basically and we give them both the knowledge and the methodology to deal with the problems. Typical example is laser technology. People who invented laser technology who build up the laser machines the first ones never learned about lasers during their studies they learned about physics, about mechanics, control theory, they learned about design and then someone had an idea and they were able to transform their basic knowledge into a new field. And that is what we are heading for in university to give the students the ability to deal with the first job and then five years later to deal with the second job, and the third job and the we have to make them fit for the next fifty years of technological improvements to deal, to understand, to develop and to further enhance. So that's what we give them. What I think- what I expect them to take. Yeah? The knowledge, the methodology and also the courage to use it. That's also something we give them to know-maybe it's not easy but do it. Do it thoroughly, think about it twice but then trust on what you can [do] what you know and risk something. Go ahead. So that's what we give them; that's what's our goal here.

MH: You've spoken quite a bit about technical knowledge and skills. Would you say that there are also non-technical or soft skills that are important in the career of an engineer or in practicing engineering?

MS: Yeah. What we do and what we did at least during my study time is that we force the guys to work in teams. In mechanical engineering it's almost impossible to survive in the studies when you go on your own. You need the others.

MH: And why is that?

MS: They have to go through a rough schedule on topics on content; they have a lot of pressure on examinations. And we train them that it's easier to learn together. We train them in projects where they can only succeed if they have one solution together where they need to arrange with other people they need to learn to criticise other people they learn to take criticism, they need to learn to think about solutions from other people in a detailed- in detailed aspects, really to go into what other people told them and then to give feedback; consolidated feedback of how to improve. Not just what do I like what do I not like but also how can you improve. And that's something we teach them on the way in the technical aspects it's not extra soft skills. And then also we have soft skills like presentations or moderating; we teach them, I do-teach them, training how to use flip charts, meta plan, how to go through creative technology to get new ideas; we teach them about the process design, not technological but business process design, so we give them along a lot of other knowledge but one of the basic things is that we bring them forward along the way to be a team player. Because they learn personally that it's easier to go together. And I think that is very helpful for them and I think the other thing that we-which is not directly soft skills but it's also-is: we train them to learn; and to learn fast, to acquire methodology how to go into a new subject very fast, to understand and to use. And this is also a soft skill in my point [of view] because it's how to learn in the future because maybe in ten years or fifteen years something new will appear and they got to do it on their own because we're not there not teach them so that's something that they learn hear during their studies and then something that is very important as a soft skill from my point of view; they learn to fail. They learn to fail, to stand up, get a little angry and then to speed up- and go again and succeed. And I think for the rest of their lives that is very helpful; to know that life goes on even [while] you lie on the ground. So that's also something that we do, not in extra, we don't have courses for that. We do that along. And those are things they learn in the technical part and also we have the soft skills of course how the methodology for making decisions and as I said business process engineering or rhetoric or presentations and these are things they have to attend and also language, learning English for example.

MH: You mentioned amongst the soft skills…that you think it's important to learn things like criticising other people, and you said your students learn this along or through the technical courses. But are there any specific pedagogical practices you use personally to promote critical thinking?

MS: ((laughs)) yes, I do but I do it in the technical content. I do not teach them how to ask questions, I invite them in my seminars or in my lecturers and I do it non-verbal. I invite them non-verbal to contradict to ask to criticise and even to allow them to say that it's wrong. So that's what I do personally. So I give them the faith that they are allowed to do and then they will do and then they will start and they will learn by doing. That's one thing I do in my classes. So we have discussions. Even if there are one hundred and fifty students in the class- we have discussions. Open discussions. For me it's important so I try to do that. One point. Second, I'm teaching design. And we do practical exercises in groups along the whole semester, and the groups have to present four times in the semester. Everyone in the course has to be at least once at the front to present. And they are not presenting to me. They are presenting to the other [students]. So I normally only ask one question maybe just to be a little bit polite. What I force the guys [to do] is to present to the group, and the group is asked to understand and then they start this dialogue. And over the semester you can see how they learn to think about people-other people's solutions, to ask the right questions, to answer these questions, to reflect on what they are doing-sometimes I jump in just to give a little bit of process help-so I like to ask the question: do you know what's happening here now? When someone is a little bit frightened or angry about the question, or if someone is not very polite or diplomatic in asking- so sometimes I jump in but it's only rare. In the most cases they start too polite and then grow during the semester to learn to talk about critical aspects; also in a diplomatic manner. You do not have to be rude. And so they learn and they learn to interact and learn to grow from being able to take criticism and to learn that it's not negative for me but it's help, to improve my product. And that's what I want-to give them the experience because I can tell that a hundred times-they will never believe and they experience it once and they will never forget. So that's one thing we do in the design classes. So it's not soft skills extra-but it's (integrated). And it's typical for the design process there is no black and what anymore there is just grey. It's true or not? Prr. ((shrugs)) depending on how you look at it. And that something they should discuss and they should go ahead in the group. That's about fifty students together so they do that.

MH: Alright; well from my discussions with masters students I spoke to in the focus groups , they said although they have to present in class, they had the feeling they were not getting prepared to communicate with non-engineers in this way; as they only present to people with similar backgrounds to them. Is there a possibility for them to gain that experience in the courses you teach?

MS: We only have five years, we cannot do everything. My personal opinion is if you are changing your mind in presenting from being happy to tell everything you know, to look if the opponent [audience] understood what you are meaning what you are wishing-if you are really addressing-then there is no difference between talking to an engineer or talking to a social science person (for instance) because they-I hope-I have a seminar with ten students – okay that's a very small group- but there I am trying to change their mind. Changing to look on the group and do what the group needs. If the group is not going with you non-verbal you got to go back to the beginning and catch them. If you-if I'm successful there-it makes no difference who you are talking to-they can go to a kindergarten and have the right words because they look at the children and they can exactly know when they got them. From my point of view there is no specific speech for target groups. There is an attitude. And then if you have the attitude, you talk to the worker, or the CEO; to the children or to the specialist. Of course you are changing, but we are all changing our language depending on our opponent [audience] every day; all day. We all are able to do it, we just have to trust. And again they have to experience that it's working and then they will follow. But then that's something I can only do with a small group because then I have to teach them I got to get them the experience so that impossible to do with two hundred students. So I do it as a general studies course with the masters students who are willing to do; but of course I could do more but I don't have more time. But that's something they think they need a different way of presenting they do not know that they do not need that. So I think that's a very important point of changing their minds, but we do not get everyone in that case but again we can-we only have limited time and from my point of view that is important but it's not the most important.

MH: Okay, and would you say that engineering graduates understand the complexity and interconnectedness of megatrends and technological innovation? That they make links between technological innovations and their resultant problems?

MS: I think they have all- all of them have enough knowledge, enough methodology to deal with future aspects. The question if they really know how to handle things according to the megatrends for me leads to well; I have no good feeling about the word 'megatrends'. Because it's very political. But we are below. We are below the megatrends in a technical aspect. We take smaller steps. We have to ask the question: what do we want to do every day? And not only depending on megatrends. And I think all the engineers that we are educating here have the ability to improve things. In different areas, not only in the megatrend areas. You know that we colleagues here talking about water supply about getting the salt out of there, for example. We have other people who are in bio ceramics. We have people who work on machines on rehabilitation and also on production machines and also on classical chemical processes and also on classical material sciences there are many aspects you never know in advance if it will be helpful in research. But in general, I think that all the engineering students have the opportunity to do something for the society. Not all the things they do will be understood by society. But maybe in some cases that is the problem of society because you see in the society what is discussed in public. And things that are running or too complex are not discussed. But they are important anyway. The question is what is more important-cleaning the water or making a car safer? Build new pipelines or reduce fuel amount? There are a lot of hidden tracks in engineering, in engineering science, people do not understand. One of the greatest challenges we have, in Germany at least, is the nuclear question. And you know that we went out of the nuclear programme and someone told in politics we shut off the nuclear plants. Shut of the nuclear plants takes twenty to twenty five years, you cannot shut them out.

MH: It's not like a switch

MS: It's not a switch; they have to be cooled down, its technological high end process first of all. But then we only have very few students who are studying nuclear technology now because it's not popular and you have to defend yourself, we do not teach that in Bremen we only have a few- a very rare group, but we all want to have x-rays at the medical area, and that is nuclear power too. And a lot of things we have there including all the garbage we are producing there a lot of it comes from the medical part. So the question if you are dealing with the right thing depends on what people know when you're talking to them and this is one extreme example where you can see that we only have a limited number of nuclear engineers now, and now we have a lack of them because we also have to in the future deal with the problems but its political incorrect so its difficult. And you have a lot of aspects like that so I suppose engineers have the knowledge and have the abilities. But everyone has to decide on their own, what he will spend his time on and that makes the question that you have been raising very difficult to answer because there is no yes or no. There is an option. Here is an option.

MH: We have just spoken about megatrends, and you said you don't like this term; so what is then your view on the concept of sustainable development and the role that engineers play in this regard?

MS: Okay, I now, I raise a question and you can think about it: what is sustainability? What does that mean? Does that mean that we do not use any energy anymore to keep the planet stable? Do we all want that? Does that mean that we do not produce any garbage anymore? Does it mean that we?- you can put on…

MH: yeah

MS: The question what is sustainability is not really answered right now. Sustainable, could be for example, a complete construction out of steel. Because you can melt steel, you can re-use it; endless times. Now we have carbon fibre, recycling of carbon fibre, may be difficult. We are heating now with wood; that is a nice idea as long as we are not using more than is growing. We are using bio energy, and killing places where food could grow. The question is very difficult to answer, what is sustainability. What we could do, and what we do is that we could give students the idea that there is something they should take in mind; but on the other hand there is actually the fact that we had a lot of trends where great hazards have been [fore]told, the trees are dying due to all the sodium things we have in the air, changes were slow and the whole procedure disappeared and later I learned someone from the agro. [agriculture] business, they had forests for generations in the family and he told me that they know this phenomenon, its appearing every eighty years. And we have other things where you see that the political discussion is on the way with easy questions and easy answers. And later, as scientists we learnt, wrong question, wrong answer. So I will not tell students to follow the megatrends. What I will try to give students is to follow, to really think, to really think about what they are doing, and then to trust on what they learn from the basic connections in natural sciences. A lot of things that are discussed now are again without thinking about the risks. Thinking about wind energy, and we're putting the windmills in the air. And of course we are changing the flow of the air. No one knows what implications we have. Probably none. But then you know that years ago there was a book that people said that if (   ) is moving it can cause a hurricane. Just because there is a small change and that give [result in] something different. We do not understand the principle, the concept the whole complex principle of nature, and neither of how the earth is running. We do not know about water flows, we do not know about wind flows we do not know about a lot of things. So what I can give the students is: always to be aware that they have to make decisions based on what they know and to try and be thorough about what they do, to be careful, to rethink- but then to decide. And to know that they may be wrong. And the only thing I can teach them is that they are- in the moment they decide-sure that it's the best that they can decide at that moment. We cannot do more. You can't, I can't, we all can't. And all the rest is marketing; it's easy answers for maybe wrong questions. But to give people confidence in decisions and none of has, we do not understand it right now, so what is sustainability? What do we want? What is the right decision when you've got to decide between two options? Look on Germany, we are going out of nuclear power, and instead increasing carbon output. So what is right? Short term- carbon output will have an impact. Long term- nuclear garbage will have a bigger impact, or maybe not. No one knows. So that's one of the things that engineers have to make decisions in an insecure environment. And not just the natural environment but decision environment and they can try to make it out to get as much information as they can to try to get a good judgment but finally they have to live with the situation that they have to decide and they may be wrong. But someone has to decide; we have to go ahead so that is what I am talking about to say sustainability, I say think about everything that may come from your decision. But as you do not know decide because you have to decide.

MH: despite the fact that you cannot predict the consequences of your decision might be…

MS: Despite the fact and *because* of the fact that you do not know. That's the reason you have to make a decision in a grey area. And a probability is still a probability. Probably this is the best one but you look to Chomsky, he said that prognosis is extremely difficult especially if it is looking into the future. And exactly that's the point: discussing now about the future, we do not the implications, we do not know the relations, we do not the correlations. We do know only a very limited, the small aspect of nature so we have- in sustainability I think people make a lot of wrong decisions and we all can [only] hope that we can correct them. That's the point. But what is the right decision? How many people shall we have on earth? How many can we feed? I mean come to the huge questions. How do we get all of them pure, clean water? How do you get all of them medical services? How do we do as long as people are so stupid- they try to control people just by taking them away from education, medical services, clean water, even houses. So I mean of course these are the huge challenges we have in the world; but on the other hand everyone has to work in his near surrounding to make the world better. Because we will not make these topics on the long term and we have still polio. We have still malaria. We have still AIDS and a lot of people not in any case in a medical service even in areas where medical service is available- because they are not allowed to take it due to religious stuff, or traditional stuff or whatever- and I from my point of view I cannot understand that we now have polio again in Somalia it was gone it's now again there, so- and these are things that are also sustainability. For me a huge amount of sustainability is water, its medical, and its food. These are the three basics. And the next is, I discussed with my son because he had in biology in school his second degree, he learnt that those trees are important because they produce oxygen. And then we were discussing about rain forests and he said why don't we go there and tell them not to do that? Again we are at one of the basic problems of sustainability; is in the world we do not have a common understanding of what we want. So I now come back to what do I tell my engineers? Do the best you can, depending on what you know. And depending on the abilities you have at the moment choose in your range the probable best solution. But then, when I studied there was this discussion about coal energy production and in Germany we had very strict limits on all the things that have to go out sulphurs and whatever and I talked to someone from the industry there and he said if we take the money that we use here to improve by well part of a percent it takes the same money to go China we can go into one hundred tons in maybe fifty percent or maybe eighty percent we can get off. So what is sustainable? Is it sustainable that we get better here in this small area or should we go somewhere else, but will the people there like if we tell them what to do? Probably not. So what is the best we can do? What is the choice you make? So that is what I want to make my students fit [for] at least I want to make my students fit for living with the knowledge that they cannot save the world alone, they can just do the best thing in the moment; from what they think, and they have to also be able to live along also if they find out it was wrong. Because they do not know. They have to make a decision. And you know that in the movie Independence Day?

MH: yes

MS: You know, where there's this guy who says that you know "we are trying to save the plant everyday now here's my chance!". Most of us will never have such a chance to save the planet so- what is better? Glass bottles? Plastic bottles? Cans? Recycling? Wasting water for cleaning bottles? Heating them? What do we do with our garbage? Are we burning it; using the energy? All these questions there is no right or wrong. There's a probability.

MH: and-

MS: so that's one of the major things and from my point of view, water, to waste water is…strange. But that's my personal opinion.

MH: May I ask why you chose to study engineering or how you got into the engineering profession?

MS: When I was in school I loved natural sciences and mathematics. And found each of the natural science too narrow. And I wanted to move things and found economics too boring too- well it's on the surface, it's not on the ground it's just a little bit too easy to- not enough in the details of the real world, so, that was the point. So I ended up in mechanical engineering because I thought that is something where we can change things, we can also change things in economics because we understand something in economics much more than economics people understand from technical science and that's what my experience was. That we need more people also in leadership who understand the details and also the connections. Who see how all the processes are interlinked between humans and things; between different disciplines. Everything is interconnected and that was my personal reason why I was in the subject because I saw that’s the subject where I can change things, really change, not talk about-but do. But do, and I think that we can do. You know that we have this “Save the World” campaign for getting new students?

MH: No I haven’t heard about it

MS: Okay so one of my colleagues had a- we- we are trying to get more students in engineering studies. And one of my colleagues had, in German it’s called “Werdet Weltretter” and it’s like translated it’s like: “go and be one of the guys who save the world”. And when I tried to explain this I say, we have different roles in society, there are people who climb on the trees to say save the trees, and that’s one role. And the engineer can say what can I invent that I do not need them [trees] anymore for my product? So I wanted to be the one who thinks about the better solution, the best solution instead of just saying I’m against it. Of course it’s important that people say I’m against but that’s not enough. That’s just the beginning. It doesn’t help us to be against everything. We got to be for something. So the question is what is it for? And that’s from my point of view the engineering subject. To be for something, to go ahead to find new things; and it’s a small very narrow border between good and bad. And it’s very difficult to judge about advantages and disadvantages and good and bad in application. And of course you can use all or every technology in war.

MH: mhm

MS: You cannot stop people making bad things by stopping engineering development. Because we use the same things in a good and in a bad manner. And so, it’s no solution to stop inventing. That is a political and societal question. Because we all want improvements in medical sciences but the more you know about the diseases you can cure them or you can use them. So it’s always a medal with two sides it’s the same with a lot of technologies, we can use the satellites to go into star wars STI for example or whatever but we also can use them to control the Border in Somalia, the border in Sudan to say they keep their peace treaty. You can say also use them to control (Ozone) or oil in the Atlantic or North Sea, we can do that. If we had all the satellites upstairs we could have been able to say where the Malaysian airline had been. The system is in plan; it’s not already there but it’s on the way. So all technology has two sides of a medal; and if people really would think about it I think they would never force to stop the invention because there are so many good things about technology. When people say technology is bad I say okay. How is your life today? What is your medical supply? What is your dentist doing? It’s engineering. Yeah? Why do we grow so old? How come so many children survive the first three months even those with heart diseases. What do you think are the machines that keep them alive during the operation? So, people do not think. As long as technology is good then it’s there. And then it’s not an engineering thing. As soon as it’s bad, then it’s technology and that’s a little bit strange in society. It’s I think in Germany its extreme. Mostly because people are so fed up, they are satisfied. That’s (the main reason) but also the safety discussion goes into engineering sciences. But people do not bring that together with engineering; it’s very interesting to see in society. Someone has to earn the money to pay society and mainly that’s invention, that’s not the pizza and…it’s not yeah, it’s not- so I wanted to be part of that group. To go ahead and do something for society in many different aspects. So that’s the background why I am here. Because I think it’s the chance to do things, not just to talk about but to do; to bring them along.

MH: Great. Then, thank you very much for your time.