Structural conditioning and mediation by student agency:

a case study of success in chemical engineering design

By

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ABSTRACT

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The study, informed by Bhaskar's realist philosophy for social science, seeks to provide an explanation for the differential success rates in a final year chemical engineering design course. Data for the study was collected over three semesters of design education. This involved observing lectures, interviewing students at regular intervals, and access to student design submissions.

Margaret Archer's morphogenetic sequence allows for the design education process to be viewed as an ongoing pedagogic interaction between students and lecturers. Furthermore, it reflects the historical nature of the education process, with events occurring over time so that past curricular events, viewed as possessing structural and cultural properties, condition student action and create a deliberative gap for student agency to emerge in social and cultural interaction. Personal emergent properties, such as reflexivity, play a crucial role as students assess their options and determine actions to mediate the structural conditions towards realising their concerns about achieving success in chemical engineering design.

The study indicates that while all students are constrained by the pedagogic practices, as defined by the values of framing both in the instructional and regulative discourses, particular categories of students are further constrained by the relationships between cultural agents, which in turn are shaped by the situational logic of the institution. Thus the latter group, identified as a group of black students, has a different educational experience in the chemical engineering design context and a narrower range of options in mediating the structural emergent properties. The less successful students in this category then determine actions for themselves which do not lead to success. The study suggests that there is a dialectic tension between students' reflexivity and other personal

emergent properties in shaping student success, which works differently for different categories of students.

Through the process of retroductive reasoning, a transcendental argument is made for why the pedagogic practices in this study have constraining features. The study shows that the lecturers concerned operate in an environment of necessary contradictions which generates a certain situational logic for them. The situational logic is one which seeks to correct the tension inherent in a system which requires excellence in research output as well as a commitment to teaching and learning. Retroductive reasoning also allows for an explanation to be offered for the differential student experiences observed, on the basis of historical social and cultural conditioning.

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'Christus Nobis Factus Sapientia'

TABLE OF CONTENTS

Chapter 1
Introduction

In a document entitled 'Educating engineers in design' Broers (2005) notes that 'the task of educating engineers for their future role is both daunting and exciting' (2005: foreword). In the same document Wallace notes that 'engineering design education is a resource-intensive activity that requires staff time and project space, both expensive' (2005a: 7). These somewhat pessimistic views on engineering design education are further elaborated on by Devon, Bilén, de Pennington, McKay, Serrafero, & Sanchez Sierra (2004), who argue that current approaches to teaching design are limited. They assert that this is due to fragmented curriculum offerings where students are exposed to design in first year and then do not see it again until their final year. The result is that they then do not have the requisite skills in terms of knowledge to engage with engineering design because it has not been systematically developed throughout the curriculum. The phrase they use for the popular capstone design course taken in the final year of most engineering degrees is 'too little and too late' (Devon et al., 2004: 1). These sentiments are worrying indeed if Shaeiwitz (2002) is to be taken at his word when he writes that the outcomes of an engineering programme are assessed through the capstone design course. If design education is fragmented as is postulated by Devon et al., can the capstone course be a fair and valid way of assessing programme outcomes?

The capstone experience takes different forms in different engineering disciplines (Jawitz, Shay & Moore, 2002). In many chemical engineering departments nationally and internationally, it is the final year design project that marks a crucial phase in a chemical engineering student's degree. It is interesting to note that those students who do not have an undergraduate engineering degree are required to go through this assessment exercise, i.e. the final year design project, in order to get Institute of Chemical

Engineering (IChemE)[1] registration. This is evidence of how highly the engineering profession regards design; a key element in a repertoire of graduate attributes.

The Engineering Council of South Africa (ECSA)[2] recognises the importance of design and names it as one of its learning outcomes. It describes this outcome as

The systematic process of conceiving and developing materials, components, systems and processes to serve useful purposes. Design may be procedural, creative or open-ended and requires application of engineering sciences, working under constraints, and taking into account economic, health and safety, social and environmental factors, codes of practice and applicable laws (Engineering Council of South Africa, 2008: 3)

Christi (2000) writes of design that it is engineering practice at the highest level; the essence of engineering. He notes however that while few engineers will experience anything other than routine design, and fewer still, leading-edge design of significant complexity and scope, accreditation requires that all graduates are competent in this area.

Peppas (1988) writes that chemical engineering design is not something picked up by experience but is a formal procedure with its own rules which can be taught in a rigorous manner. Sinnot (1993), on the other hand, argues that the intuition and judgment necessary to apply theory to practice will come only from practical experience. These authors represent the different views held by educators on the teaching of design, capturing the varying imperatives of academics versus those of professional engineers (or academics who have substantial industrial experience) on the question of process design. There are other variances with respect to approach as highlighted by Westerberg (2004). He notes that in traditional chemical engineering design unit operations[3] are combined to create a system and that more recent and innovative approaches look rather at the tasks that need to be accomplished with the available equipment. Given the above differences

1 IChemE is a professional body in the UK which accredits chemical engineering degrees.

2 ECSA and the Higher Education Quality Committee (HEQC) signed a Memorandum of Agreement in 2006 to mutual accreditation of engineering programmes.

3 A unit operation is a step in a chemical process.

on how to approach chemical engineering design, the issue of how it needs to be taught and assessed is not a trivial one.

1.1 Rationale for the Study

The issues raised above concerning the importance and nature of engineering design education aroused my curiosity after spending a short time on the staff of the Department of Chemical Engineering at the University of Cape Town (UCT). During the weekly academic staff meetings, particularly towards the end of each academic year, around the marking of examination papers (and coincidentally around the marking of the design projects), the subject of the *in*competence of students in design was a popular topic around the table. One of the problematic areas is the high failure rate in the Capstone Design Project, a fourth year design course. At the time I joined the department (2006) the failure rate was around 10% but was reportedly 20% in 2002 and 2003. Even more worrying is the fact that the students who traditionally fail the capstone design project have a history of underperforming throughout their undergraduate career so that the design course ends up fulfilling a gate-keeping function. It is the contention of some academics that this should not be the case and that such students should be 'sorted out' earlier on in the system. This is a real cause for concern as getting this far in a degree programme would seem to imply that a student is able to engage with the material at the appropriate level of complexity.

A frequent anecdote heard among academics is 'no one should be failing at this level'. Indeed, according to Christi, 'design tests and trains students in integrating into a workable design the many engineering principles learnt in the various courses' (2000: 166). Therefore something is arguably 'going wrong' earlier on in the students' education which only seems to manifest in the design project. These concerns come at a time when the department and faculty are under pressure to improve throughput-rates. For me, therefore, this issue of design failures was of real concern and required a systematic investigation into the events prior to the capstone project as well as an understanding of

the experiences of those involved, namely, students and lecturers, prior to and during the capstone project.

In taking a closer look at the problem, I identified the following four dimensions to the problem that needed further exploration:

1. Does the problem lie with students' overall design education, i.e. in the undergraduate courses preceding the capstone project?
2. Does the problem lie with the capstone project itself?
3. If the problem lies with student performance in the capstone project, what is it that students are failing to achieve in this project?
4. Why is it that it is predominantly black[4] students who are failing the capstone project? (Refer to Appendix A for a ten-year history of the failure rates in the Capstone Design Project.)

When looking further into the problem, it was evident that the capstone design project involved a number of the academic staff who conduct the assessment of student projects each, a fact that is related to point two above. The different parts of the capstone design project are marked by different academics. Therefore I was interested in how the assessment criteria were communicated among the different academics involved in the capstone course. Further, with the exception of one, none of the design staff have any industrial experience although an industrial consultant is always brought in during the assessment stage of the project. On this point, Christi contends that

Supervision, guidance and evaluation of a design project require experienced engineering judgement. In view of the professional responsibility that goes with design, a design project instructor ought to be a qualified engineer with a licence to practise…The excitement and flavour of design come out only when the teacher has participated

4 For analytical purposes 'black' in this study refers to non-white, i.e. Black African, Coloured and Indian whereas Black refers to the population group Black African.

him/herself as a design or project engineer in a commercial project of significant scope (2000: 171) .

He does however acknowledge that many professors in engineering schools have no industrial engineering experience let alone 'demonstrated' experience in design engineering.

This lack of industrial design experience on the part of most design educators raised a question for me regarding the source of chemical engineering design knowledge. If design educators do not have experience in industry, then what is the source of their design knowledge? On the one hand, this question is easy to answer if one looks at the industrial roots of the discipline of chemical engineering. The discipline developed in response to industrial needs, but the design of processes and the relevant techniques were arguably part of early twentieth century academic chemical engineering. This means there is a scientific element to design but there is also, particularly in contemporary engineering practice, concern for the economy, sustainability and climate change; there is also the 'real world' aspect to engineering design.

Moreover, as part of the scope of the capstone project, chemical engineering students are almost always asked to design processes that are already commercially available, i.e. most design projects are designs of unit processes for the production of, for example sulphuric acid, ammonia, citric acid, urea etc. This means that whatever students get to produce is already being produced in real scale and the associated knowledge has already been documented in texts. Therefore, what the design educators do is to select and *delocate* knowledge from texts, from real processes and from the engineering sciences, as well as basic sciences. This process of delocating and *refocusing* knowledge has been termed *recontextualisation* by Bernstein (2000) as part of what he calls the rules of the *pedagogic device*. This does not mean that once the students complete the project and graduate, they are ready to simply walk into a design office and start designing. Once situated in a design office they would need further education and training in the authentic work setting. All the lecturers would have done is select for the students what they think is necessary to facilitate further learning beyond the academy. This goes hand

in hand with what the imperatives of design education are, as stated earlier, namely to test and train students in the engineering principles learnt in the programme as opposed to providing work-ready graduates.

The lecturers of course are not the only *recontextualisers* (Bernstein, 2000); they are agents of the pedagogic recontextualising field (PRF). Organisations such as ECSA represent the official recontextualising field (ORF) and even though they have stipulated knowledge areas on which engineering programmes are to be assessed, they have left it to the providers (i.e. institutions of higher education) to decide how to structure those knowledge areas in a curriculum, provided the outcomes set by ECSA are met. Ultimately the agents in the PRF are accountable to the agents in the ORF.

In considering all these issues, I set out to conduct a systematic investigation of the issues presented, particularly as outlined in the four points, in the form of a PhD study. At the time I was (and continue to be) employed as an academic development lecturer in the Department of Chemical Engineering, and as such it is part of my mandate to take an interest in educational issues of the department. With this in mind, there were greater concerns for me personally that had to do with the desire to contribute to the broader community of engineering education researchers. When I thought of what my research questions would be therefore, I was mindful of prior research in the area of engineering design education (and engineering education in general), the nature of the questions asked and the methodology adopted in the studies.

A study on engineering design education conducted by Marin, Armstrong & Kays (1999) sought to characterise the optimal capstone design experience. They identified three key elements of an optimal experience, namely, student preparation, project selection and instructor mentorship. They defined student preparation as the extent of student exposure to design prior to the capstone course, and instructor mentorship as the extent of the control exercised and guidance provided by instructors to student design teams. They concluded that ‘a worthwhile project, sponsored by an active client, and mentored by an instructor who inspires the students to take ownership of the project’ results in an optimal capstone design experience (Marin et al., 1999: 21).

Other research in this area has tended to focus on assessing student performance in the capstone project. For example, Davis, Beyerlein, Trevisan, Thompson & Harrison (2008) developed a conceptual model to assess learning outcomes and student achievement in design. They developed the instrument in response to a perceived need for transferable assessment models to account for a variety of capstone design courses. Their research identified four performance areas that describe the design experience, namely, personal capacity, team processes, solution requirements and solution assets. In developing the model their intention was to provide a means of making achievement targets clear in order to measure performance differences in design. They argue that the strength of the model is its basis on 'clearly conceptualised cognitive models of learning that reflect the most scientifically credible understanding of ways learners represent knowledge and develop expertise in the domain' (Davis et al., 2008: 2). In a study on the teaching of capstone design, Dutson, Todd, Magleby & Sorensen (1997) sought to describe standard practices with respect to capstone design education. Some of these practices pertain to design student teams and the involvement of faculty. They found that in capstone projects which encouraged team work, student interaction in student teams was one of the most important aspects of the capstone experience. Moreover, they found that an instructor's level of interest or involvement in the capstone course is influenced by the amount of time they can invest in the project without taking too much time away from their research activities which, they note, are the 'major vehicles of faculty advancement or promotion' (Dutson et al., 1997: 20).

The studies cited and others in the area of engineering education generally tend to use surveys and questionnaires as data gathering instruments and employ quantitative data analysis techniques. The concerns they address with respect to the design experience are similar to the four points raised on page 4 such as what happens prior to the capstone course in terms of design, as well as student performance in design. However, these studies seem to limit the major stakeholders in the design experience to the students and their cognitive capacities, to faculty and to industry partners (for those projects which included this component). Dutson (1997) above begins to hint at the fact that there is

another stakeholder within the academy – such as the institution itself, its research agenda and promotion structures - with the capacity to influence faculty involvement in capstone design activities and therefore the design experience as a whole.

Therefore, while the questions asked in engineering design education research attempt to be relational, they 'do not cast the net wide enough' with respect to potential factors that influence the design experience. Further, while most do refer to individual students or student teams, the only aspect of 'the student' that is deemed to be real and worthy of analysis is their cognitive capacity and the value this adds to the capstone design experience.

The issue of the type of research questions asked in the area of engineering education in general has been taken up Radcliffe & Jolly (2003) who give a good summary of recent trends in engineering education research. They argue that the area of engineering education research has struggled to frame studies for three primary reasons. Firstly is the issue they have termed *technological determinism* where attention to innovation in teaching practice seems to be concerned with 'technology with enormous potential looking for an educational problem to solve' (2003: 2, session 1630). They argue that while technology has made huge contributions it needs to be viewed as a means rather than an end.

Secondly is the issue of what they call *lone enthusiasts.* These are usually individual faculty members who, motivated by the desire to improve student learning, or to respond to changes in student intake, implement teaching innovations. While these innovations are always inspired by something, more often than not they are reinventions of previous efforts and they rarely diffuse and develop. Radcliffe & Jolly further note however that few of these faculty members derive their inspiration from aspects of their own research work. While in principle I agree that the *lone ranger* approach does not foster collegiality, I have known quite a number of them to thrive. More problematic is perhaps the uncritical spirit in which some of these innovations are taken on. As Elton puts it, 'the main aim in staff development consists of getting teachers in higher education to get to

the point where they bring to their teaching activities the same critical, doubting and creative attitude which they bring habitually to their research activities' (1987: 57).

The third issue is that of *practice without theory.* Radcliffe & Jolly note that 'the practice of teaching and learning in engineering schools has been notable for the almost complete absence of any underlying pedagogical model or theoretical framework' (2003: 4). They cite as problematic the lack of a philosophy of engineering such as exists in science, mathematics and medicine. They further note the paradox inherent in the fact that engineering education is preoccupied with teaching about models and theories, but that educators in the field do not see the need to develop and discuss the models and theories of student learning underpinning their teaching practice. This is exacerbated by the narrow focus of the literature in engineering education, which, they argue, has much to learn from the wider philosophical and empirical literature in higher education. Engaging with wider literature is a double-edged sword in that it opens up more fundamental questions about our understanding of knowledge and learning issues, as well as issues of social structure and power. Fortunately however there have been materials produced whose purpose is to make the process of engaging with education research much more manageable for the new-comer (see, for example, Case, 2008).

Another issue for me, in thinking about the PhD study, had to do with dissatisfaction with trends that adopt only psychological theories in researching student learning, such as the cognitive view where 'learning is the acquisition of structures that are stored in memory and are or are not retrieved and applied in new circumstances' (Greeno, 1997: 12), a position endorsed by, for example, Anderson (1983) and colleagues (Anderson, Reder & Simon, 1997). Moreover, while I do think there is value in theories that tell us how individuals learn by referring to participation and interaction with others in activities (such as in the situated tradition endorsed by Greeno), I wanted my unit of analysis to extend beyond an individual's cognitive structures, or different participatory situations (although Cobb & Bowers (1999) caution against reducing these two perspectives to choosing between the individual and the social collective as the primary unit of analysis). There is also no question that in the chemical engineering programme, students

individually interact with materials and the lecturer, as well as participate in group activities. My interest in looking at the problem was to view those events as occurring within or in the context of a range of broader structural, social and cultural considerations, each of which has the capacity to further enhance performance or to hinder it.

The theoretical perspective chosen therefore provided the background for conceptualizing enhancement and hindrance, i.e. *enabling* and *constraining*. More detail on this is provided in the following chapter. My theoretical choices meant I was able to look at issues such as curriculum structures and knowledge structures as they influence student learning. The framework further meant that I was able to achieve coherence between ontology, epistemology and methodology (Crotty, 1998).

Considering that the students who get admitted to the chemical engineering degree are usually students who throughout their schooling have demonstrated high levels of academic aptitude, it seems to me that when a programme does not achieve the level of success it should, particularly when a designated group consistently seems to fall short, the theoretical tools that are used need to transcend psychological approaches (indeed even social psychology). Research with regard to the extent to which matric scores[5] are good predictors of success in engineering does not give a clear picture. In the South African context for example, Foxcroft & Stumpf (2005) note that matric results are not good predictors of success in higher education. Van der Flier, Thijs & Zaaiman (2003) indicate that matric results are a good predictor of success for students from educationally disadvantaged backgrounds when used in conjunction with entrance tests. This evidence indicates that contemporary engineering educators, certainly post-apartheid educators, are dealing with a student body that is diverse in ways that go beyond race. At UCT students admitted to chemical engineering are traditionally students with the highest matric points of all students in the faculty. Therefore, if we are admitting students who could be expected to succeed and yet do not, then in researching issues

5 These scores are those obtained by students in the final examinations in their year twelve of school and refer to a process of becoming eligible to enter higher education by meeting a set of criteria.

concerning student learning, one should view learning as occurring in cultural, structural and social contexts, the nature of which may have consequences for learning and academic success.

The main research question has therefore been developed with the above context and rationale in mind, as well as taking into account the theoretical contribution.

The purpose of this study is to understand why things turn out the way they do in the Capstone Design Project, that is, why the failure of a group of black students persists, and to offer a layered explanation for this phenomenon. Among those who graduated after Year 2 of the study, eight students failed the final year design project and all of them are from previously disadvantaged backgrounds.

1.2 Thesis Roadmap

The thesis is organised in the following order. Chapter 2 presents the conceptual framework of the study. These theoretical tools were instrumental in formulating the research methodology and design which are presented in Chapter 3. The adopted methodology is Margaret Archer's morphogenetic[6] cycle which is introduced in Chapter 2 and elaborated on in Chapter 3. Chapter 4 presents the context of the study in terms of the structural and cultural conditions. This chapter represents the first stage of the morphogenetic cycle. The social interaction[7] stages which, according to the morphogenetic cycle, follow the structural and cultural conditioning phase are presented in Chapters 5, 6 and 7. Each of these three chapters represents a semester in the students' education. Since this is a longitudinal study (in response to point 4 on page 4 above) the students' experiences needed to be tracked across three time periods. Chapter 8 is the discussion chapter which ends with some concluding notes. The concluding notes make some reference to structural and cultural elaboration (or

6 Unless otherwise stated, the phrase 'morphogenetic sequence' is taken to mean morphogenetic or morphostatic sequence. Any declaration of structural or cultural elaboration (i.e. morphogenesis) or reproduction (i.e. morphostasis) will otherwise be made clear.

7 Where the study refers to 'social interaction', this also implies socio-cultural interaction in keeping with structural and cultural considerations. Margaret Archer uses social interaction with structural considerations and socio-cultural interaction with cultural considerations.

reproduction as the case might be) which again is consistent with the morphogenetic cycle.

Chapter 2
Conceptual Framework

The previous chapter provided detail of the central purpose of this research which is to provide an explanation behind the phenomena observed in the chemical engineering design course in fourth year, an explanation which takes into account the trajectory of students through the design course and through prior design courses. My desire in choosing a conceptual framework was to find one that would allow me not only to describe the interactions, relations and experiences observed in the chemical engineering design contexts, but also to offer an explanation. This means I am interested in uncovering the relationships among the observed phenomena, (as well as the experiences of these) and thus to clarify the causes, contexts and consequences of those facts[8]. In keeping with this therefore this chapter will give a breakdown of the meta-theory and related concepts that underpin this project.

According to Glatthorn (1998), the purposes of conducting any research project are to generate and disseminate knowledge. More specifically however, Richey and Klein (2007) assert that most research can be viewed as being exploratory, descriptive or explanatory. Some studies, such as this one, aspire to do two of these, that is to first describe and then to explain. In aspiring to describe and explain, my intention is to describe the educational contexts that I observed and the interactions prevalent in those contexts by reinterpreting the subjective experiences of my participants, which were interpretations of interactions. In addition to describing, my intention was then to posit an explanation for the events observed and the interpretations offered by participants. This would allow me to put forward a suggestion for why things appeared as they did and not otherwise (Archer, 1995), thereby generating useful knowledge of the world.

Lopez & Potter (2001) argue that questions concerning what we know depend on what there is there to be known; 'epistemological questions are dependent upon ontological answers to questions about the nature of existence' (2001: 10). Therefore, inherent in my

8 Facts as defined by Bhaskar (1989) are historically specified realities.

intentions described above, is an implicit idea about the nature of the reality with which I was dealing. The issue then was to choose a framework that could account for that reality (Maton, 2001), despite the lack of knowledge of its particular nature. As Bhaskar puts it, 'All philosophies, cognitive discourses and practical activities presuppose a *realism* – in the sense of ontology or general account of the world – of one kind or another' (Bhaskar, 1989: 2).

The philosophy that underpins this study is *critical realism*. It is described by Lopez and Potter as a 'broad church', where intellectual differences exist among those who call themselves critical realists (Lopez & Potter, 2001: 15). Some of these differences, for example, are about the concept of structure, the relations between structure and agency, and the extent to which social structures have causal mechanisms. As a philosophy it offered me the ontological and philosophical foundations which I sought. Danermark, Ekstrom, Jakobsen & Karlsson (2002) contend that the 'explanation of social phenomena by revealing the causal mechanisms which produce them is the fundamental task of research … in this explanatory endeavour *abduction* and *retroduction* are two very important tools' (2002: 1).

Danermark et al. define abduction as an 'inference or thought operation' (2002: 205) where an event is interpreted using a theory. Retroduction is about 'reconstructing the conditions for something to be what it is' (Danermark et al., 2002: 205). It is a *transfactual* reasoning method where one seeks qualities beyond what is immediately given. In this study abductive inference provides the descriptive role while the core explanatory function, with respect to reconstructing the conditions for the event to occur, will be provided by retroductive reasoning.

This discussion will highlight those concepts that I have applied to this study and at the same time will serve as a declaration of my stance with respect to some of the contested areas, in as far as they pertain to the study. After the discussion on realism I turn to the work of Margaret Archer and Basil Bernstein, and again will concentrate on those concepts from their work that I applied to the study.

2.1 Critical Realism

Bhaskar's realism (Bhaskar, 1989) argues for a world that is structured, differentiated and changing. According to Lopez & Potter (2001), this philosophical development was a reaction to positivism, an epistemological position which rested on the notion of actualism for its ontological base. The positivist position claims that all knowledge is empirically derived, that is, experience is the sole source of human knowledge (Forrester, 2010), and through the process of observing the constant conjunctions of events (that is, repeated experiments confirming associations between two or more events or variables) invariance is established from which in turn causality is inferred. Therefore, according to this position, all reality consists of only the actual and the empirical, with the latter being a subset of the former (Lopez & Potter, 2001). The empirically observed event is generalized to all events (all events being the totality of all including those not observed, hence the actual) and considered to be 'exhaustive of reality' (Lopez & Potter, 2001: 11).

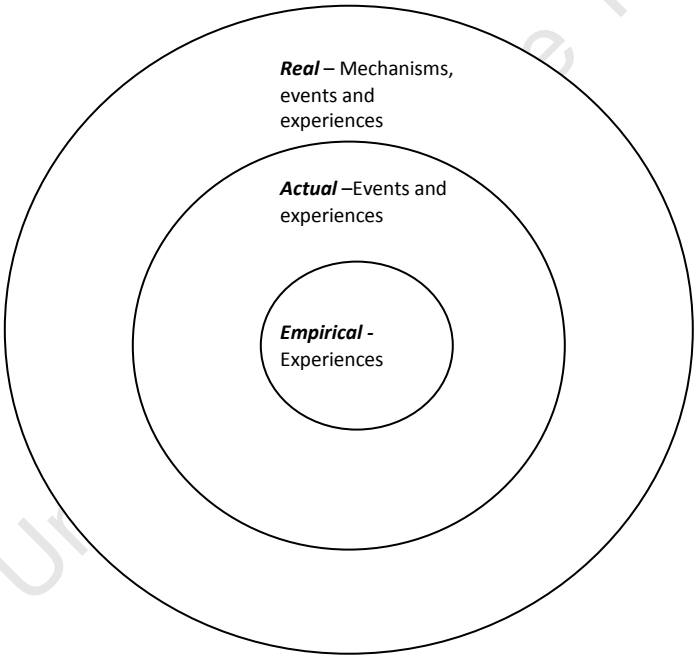
Critical realism was also a reaction to post-modernism, according to which reality is socially derived, a product of discourse (McGettigan, 1998) and where knowledge is anything human beings certify as such (Younkins, 2004). Equating knowledge or reducing it to direct experience is, according to Bhaskar (1989), committing what he has termed the *epistemic fallacy*, where the world is reduced to our knowledge of it. While the realist epistemology is also committed to a view of the socially constructed nature of knowledge, therein ends the similarity with postmodernism. The word 'production' is preferred by some realist texts (see for example Lopez & Potter, 2001: 9) over 'construction' (Bricmont, 2001: 97). Critical realism is not only committed to actually occurring events as constituting reality, but potentiality, or unexercised causal mechanisms are also viewed as a crucial aspect of reality (Lopez & Potter, 2001). In this way, realists view reality as stratified and consisting of the real, the actual and the empirical.

The real encompasses both the actual and the empirical but further consists of the generative or causal structures and mechanisms which are not observable but whose

effects are felt nonetheless, i.e. they are independent of mind and society in the sense that they operate regardless of whether anyone is aware of their existence or not (Bhaskar, 2008). Furthermore, Bhaskar argues that these structures are distinct from the pattern of events that they generate. The domain of the actual comprises phenomena, events or outcomes which are caused by these mechanisms and which may or may not be triggered and may or may not be observed. The domain of the empirical consists of that which is the experience of the observer.

Figure 1 represents the relationships between the three strata (Elder-Vass, 2004: 3).

Figure 1: The three domains of reality



Structures at the level of the real possess powers which, while possessed, may not always be exercised; or exercised but are not always actualised and finally, even when actualised, are not necessarily always perceived (Collier, 1998). Collier further argues that stratification also means that lower strata are then able to explain those at the higher levels. This allows the researcher to explain actual educational events or phenomena by appealing to a range of structures at the level of the real.

Danermark et al. (2002) stress that mechanisms at one stratum (e.g. the actual) are formed by the effects of the powers and mechanisms of the underlying stratum (the real), but that these mechanisms represent something new and are qualitatively different from the mechanisms and structures which generated them. These newly formed mechanisms have their own distinct powers. This occurrence gives rise to the idea of *emergence* such that we can say the newly formed mechanisms have 'emergent powers' (2002: 60). Emergence is defined by Elder-Vass (2004) as that property which makes it possible for the whole to be greater than the sum of its parts. The newly created 'thing' is not simply a combination of the elements from a previous stratum. Instead, these elements from the underlying stratum must have a distinct relation to each other which gives rise to qualitative changes.

In realist terms therefore, structures and the mechanisms that generate phenomena are the objects of knowledge in this study and according to Bhaskar (1998) it is through the activities of social science that this knowledge is produced. Bhaskar further points to another dimension of the real, to which he argues realism directs our attention, and that is the realm of the structure of social relations. He argues that these structures of social relations are the explanatory key to understanding events (Bhaskar, 1989). The discussion now turns to the issue of social structure as it is implicated in critical realism and the ideas of stratification and emergence are further developed.

2.2 Structure and Agency

An interest in pedagogic interactions in the context of chemical engineering design requires both the foregrounding of people as the agents of the interactions, as well as the contexts in which these interactions take place. Sociologically this problem will be framed as one of structure and agency. In broad terms, the aim is to demonstrate that the actions of lecturers condition what students can do, but that lecturers in turn are conditioned in their actions by other broader contexts. The concepts of stratification and emergence, introduced earlier, facilitate this discussion and have methodological implications which shall be addressed.

The basis of the following discussion is indeed that social reality can be viewed in the same vein (in terms of the unity of method, see for example Archer, 1998b) as natural reality. This condition is termed by Bhaskar the *possibility of naturalism* (Bhaskar, 1998), where he asks whether it is possible to apply the same rigour in researching the social sciences as in the natural sciences. Archer addresses this by noting that critical realism accepts the ontological difference between social and natural reality, particularly if unity of method 'is taken to be synonymous with a unity of methodology in the positivist tradition' (1998b: 190).

In realist terms, society consists of people and social relations (Danermark et al., 2002). As Bhaskar puts it 'the relations into which people enter pre-exist the individuals who enter into them, and whose activity reproduces or transforms them; so they are themselves structures' (1989: 4). The *peopled* nature of society means that a social system is an open system (Archer, 1998b). Archer notes that what distinguishes a closed system from an open system is, for the latter, 'people and their own inalienable emergent properties' (1995: 70). Moreover, according to Danermark et al., these social structures have emerged from human agency and have properties of their own. Sayer (1992 cited in Danermark et al., 2002) is quite careful however to warn us that we need to separate structure from the people (the agents) who at some point or another occupy its positions and practices. This separation implies that social reality is stratified (Archer, 1998b) and that the people have their own emergent properties (in an open system) whose actions are not determined by structures. According to Archer this stratification implies that these emergent *properties and powers* are particular to people and include reflexivity about any social context they confront.

According to Archer (2000a), however, the validity of analytically separating structure and agency has been a long-standing debate in social theorising. In conceptualising the structure and agency debate, Carter & New describe the realist perspective as follows: 'an ontology of persons and relational structures, each with their respective emergent properties and powers, contingently combining to produce second and third-order

emergent properties, implies that the social world is not merely differentiated, but also stratified' (2004: 7 - 8). In the same manner in which emergence has been described above, these new properties and powers[9] that result from the interaction between persons and social structures (each with their own powers and properties) are more than the sum of their constituents. This has several implications, namely, that emergent properties are irreducible to each other and have the potential to modify their constituents. According to Danermark et al. (2002) the irreducibility of social structures to agents or *vice versa* is such that structures and agents belong to different strata and as such each possess different powers. Furthermore, emergent properties occur in time, have relative autonomy from each other and exert independent causal influences (Carter & New, 2004; Zeuner, 1999).

The structure and agency relationship has been conceptualised differently in non-realist theorising. According to Carter & New (2004) there is the structuralist view where causal primacy in explaining the social world goes to the role played by social structures. This leads to a diminished view of agency which Archer calls the over-socialised view of man[10]. As she puts it, 'man becomes such a dependent insider that he has no capacity to transform his social environment' (Archer, 2000b: 11). In this view then all social processes originate at the level, not of individuals, but rather of structures and their interrelations. This view has historically been criticised for its perceived structural determinism (Whimster, 1983), i.e. by emphasising the importance of social settings in determining and constraining free will. More specifically, Archer argues that this view fails to account for why people seek to change society's rules, something which she argues originates in people's concerns, 'forged in the space between the self and reality as a whole' (Archer, 2000b: 12).

9 The phrase 'properties and powers' tends to be one that Archer uses as opposed to Bhaskar, who writes mostly just about 'powers'. Either way, what this refers to are the newly emergent phenomena which are different in character to those entities from which they emerged, both in terms of what they are able to do, i.e. powers, or are characterized by, i.e. properties.

10 Man here is used in its generic sense to suggest 'all human beings'.

Finally, structure and agency relations have been studied from the *structuration* approach where structures are viewed as virtual and only existing to the extent that they can be instantiated by agents (Carter & New, 2004). Structure and agency then are seen as mutually constitutive with neither awarded explanatory primacy. As Carter & New put it, 'the properties of structure and agency are only real in conjunction with each other, and cannot be examined or identified separately since not even an analytic separation is possible' (2004: 5). The non-realist conceptions then tend to accord explanatory primacy to either structure or agency (or to neither, as in the case of structuration) where either the one or the other (or a conflation of both) is seen to exercise properties and powers.

Archer's objection to the structuration approach is its assertion that structural conditions are mere internalised rules and that individuals have the freedom to act differently at any time. Archer notes that this creates a false impression where 'systematic underplaying of constraints artificially inflates the degrees of freedom for action' (Archer, 2010: 234). According to King (2010), Giddens' assertion of individual freedom creates a 'curious and unresolved oscillation between determinism and voluntarism in Giddens' work because he fails to maintain a distinction between the individual and social reality' (King, 2010: 254).

The relationship between structure and agency (as detailed above) has implications for the conception of structure advanced. In realist terms, structure is viewed as systems of human relations among social positions. It is

> *A nexus of connections among human actors causally affecting their actions and in turn causally affected by them…the causal effects of the structures on individuals is manifested in certain structured interests, resources, powers, constraints and predicaments built into each position by the web of relationships (Porpora, 1998: 338).*

However, these positions have to exist prior to their occupancy: 'the new set of internal relations into which they are then embroiled exert a *sui generis* conditional influence upon them' (Archer, 1998b: 202). Non-realist conceptions of structure have been criticised from a realist standpoint (Archer, 1995, 2000b; Porpora, 1998) for failing to acknowledge the independence, pre-existence and causal efficacy of social structures.

Further, these structures represent the material circumstances in which people must act and which motivate them in certain ways. Porpora argues however that to assert that positions structure interests which in turn structure actions is not deterministic since actors may fail to recognise their interests and even if they do recognise them they may choose to act against them in favour of other considerations. He concedes that actors often act in creative ways that cannot be predicted in advance. Structures therefore have a material existence which is prior to the actions of agents (Porpora, 1998).

The foregoing discussion has implications for explaining social reality. These are such that in using a critical realist framework one should aim to move from the level of the actual or empirical to the generative mechanisms which are the cause of such events. In this study the phenomenon being investigated is the persistent unsatisfactory performance, in chemical engineering design, of students from the same population group.

Moreover, a realist approach demands that in searching for causal explanations - in this research - I need to take account of the students' own perceptions of the chemical engineering design teaching and learning context (where the interaction unravels), as well as the meaning and value these add to the students' learning. In other words, reading Danemark et al. (2002) suggests to me that my participants' interpretations of reality are also my objects of study, regardless of whether they are false or not, contradictory or even unreflecting. This combination of causal explanation with a hermeneutic orientation ensures that having understood 'the material setting and the … meaning of a social practice, we can hope to understand peoples' options in relation to it and thus their reasons for acting in the ways they do' (Carter & New, 2004: 4). I seek to understand what certain actions mean to actors but also to understand why certain things happen in particular ways in the social context of interest. Finally, in order to avoid committing the epistemic fallacy – equating epistemology with ontology - I cannot confine my investigation to the interpretation of people's experiences and events observed but will look at issues beyond agents' immediate experiences or knowledge as possible causes for events observed.

2.2.1 Pedagogic Structures

Danermark et al. (2002) argue that social structures can be analysed at all levels and in any area: 'organisation structures, small group structures, the social structures of the dyad or triad, the structures of street life, communication structures, linguistic structures and personality structures and so on' (2002: 47). Archer is more nuanced in her position on the issue of levels of analysis and, in keeping with her realist orientation, uses the term *different strata*. The implication is that in the same manner in which structure and agency represent different strata, a social structure can conceivably be made up of other structures which are notionally smaller than the original structure.

Structures have been defined as past practices of agents which endure and as such have conditional influence on later agents' actions. Pedagogic practices will, therefore, be conceptualised as entities that are structurally conditioned and in turn, possess powers to condition student action. Further, using Archer's notion of level of analysis suggests that these pedagogic practices are emergent properties which themselves have emerged from other structures, be they institutional, faculty or departmental structures. Moreover, in order then to understand the potential conditioning influence they may or may not have it is necessary for me to describe their properties. For this I found Bernstein's conceptualisation of pedagogy most useful. These pedagogic practices are material and social practices which are observable and amenable to description. They therefore represent what 'actually' happens in lecture theatres and in lecturer-student interactions in one-on-one settings.

Bernstein (2000) argues that pedagogic practice can be analysed as a form of cultural relay and that its inner logic is provided by three rules, namely, evaluative rules, selection, sequencing and pacing rules, as well as hierarchical rules or rules of social order. The hierarchical rules pertain to how students are expected to conduct themselves in different pedagogic contexts, be they lecture theatres, design studios or offices of academic staff for one-on-one consultations. Students in chemical engineering design are expected to a) distinguish between the different aspects of the curriculum, e.g.

understand what 'thermodynamics' is about and why it differs from 'mass and energy balances' or 'design of fluid flow systems', b) be able to select from these aspects those that are relevant to the design they are given and c) to use these different aspects to produce a design that demonstrates their competence. Theoretical language used by Bernstein would phrase these as a) recognising or distinguishing between contexts (or categories), b) selecting relevant meanings and c) realising appropriate text[11]. Bernstein further notes that if a student is able to do a) they have *recognition rules*, whereas b) and c) entail possession of *realisation rules*. Morais & Neves (2006) add that if students can do all three they have active realisation but if they can only do a) and b) they have passive realisation.

These rules pertain to text production in the capstone design project and, according to Bernstein's language, their acquisition is regulated by the different pedagogic contexts to which students are exposed. To leave the matter there, however, would be to give primacy to one lens, that of structure. If for a particular student the context does not enable her to infer the rules, whether because of the context or because of the frame of reference the student brings, the student has to deliberate over this at some level (has to decide what to do, take action etc.), otherwise she runs the risk of producing inappropriate text, and potentially failing the course. Alternatively, if a student is able to infer rules despite the context, there is presumably some deliberation over this that also might happen. Therefore, these rules have also to be seen to be mediated by the students themselves. The point to be made is that the 'objective' contexts and mechanisms do not directly 'give' the potential rules to the students but rather the students subjectively mediate the contextual particulars as they regulate their own learning. This latter point is Margaret Archer's language for giving due consideration to the role agents (students) play in mediating structural properties and powers.

11 For the purposes of the study text does not only refer to written text but includes behaviour, knowing how to conduct oneself in certain situations, what to say and how to say it.

The recognition rules provide the means to distinguish between contexts and as such the specificity which constitutes a context while realisation rules provide the means to produce appropriate texts within a given context (Morais, Fontinhas & Neves, 1992). Bernstein argues however that these rules are defined by the values of *classification* and *framing*.

Classification is a concept used to define a relation between categories. These can be categories of courses, discourses or agents. If the categories (of courses for example) are specialised, they have their own specific boundaries and identities, i.e. are separate from each other. This specialisation is maintained and reproduced through preserving the gap or the insulation between the courses. If this insulation is strong, this is termed a strong principle of classification. Conversely, if the insulation is weak, the principle of classification is described as weak. According to Bernstein, (2000), it is power relations which establish and maintain the insulation. Weakening of the insulation, which Bernstein maintains happens through integration, can pose a threat to established identities. Strong classification allows easier reading of recognition rules, i.e. if contexts are well bounded from each other a student is in a better position to distinguish one context from another than if they are integrated.

Framing is about forms of control that regulate and legitimate communication in pedagogic practice and it is always linked to classification. If classification is about the relations between categories, framing is about the social relations within the categories (Hoadley, 2008). Hoadley further notes that framing 'is about the controls on communications outside the pedagogic practice entering that pedagogic practice' and refers to the location of control over the rules of communication (2008: 16). In other words, framing seeks to answer the question of where control is located within pedagogic practice. If it is located with the educator, then the framing is considered strong as exemplified by the fact that students have very little control over the sequencing (how the course contents are structured and what is covered first then second etc), pacing (how quickly the teacher covers each section and therefore how quickly the students

need to understand material), selection (which contents are covered) and evaluation of the knowledge learnt (the extent to which the lecturer makes clear to the students the criteria by which they will be evaluated). These four elements - selection, sequencing, pacing and evaluation criteria - are the key aspects of the transmission[12] context or the instructional discourse. Their strength or weakness is evaluated by the values of framing.

According to Hoadley (2008), classification and framing describe the structural and relational aspects of pedagogic practice and expose the power and control relations inherent in it. If these structural and relational aspects change from weak to strong or *vice versa*, then there will be changes in several other structures including organisational practices, discursive practices, transmission practices, as well as in conceptions of the teacher, the student and knowledge.

Bernstein, in writing about recognition and realisation rules, points out that subjects are only able to produce appropriate text if the principles of classification and framing are such that they enable students to distinguish between contexts and to produce appropriate discourse (through the nature of the control in the pedagogic relation).

According to Bernstein the concept of framing refers to the control over two discourses, namely, the *instructional discourse* which is embedded in the more dominant *regulative discourse*. Hoadley (2008) notes that the instructional discourse refers to what knowledge is transmitted, and the regulative discourse refers to how knowledge is transmitted. The sequencing, pacing and the evaluative criteria form part of the instructional discourse whereas the rules of hierarchy form part of the regulative discourse. The hierarchical rules reflect the relations of control between lecturer and a student giving rise to two modes of control namely positional or personal control. As Gamble & Hoadley put it

12 This term is common in the writings of Basil Bernstein and is almost always accompanied by the term acquisition to capture the logic of any pedagogic relation. Therefore its use in this study is always associated with Bernstein and defines a process where the teacher passes on information to a student, who is then the 'passive recipient'. This is in accordance with the arguably structuralist orientation of Bernstein's theory.

> *The distinguishing feature of positional control was taken to be that inter-personal and intra-personal features of the control relations were not the explicit focus. …Personal control was deemed to focus explicitly on transmitter and acquirer as individuals, rather than explicitly upon the formal statuses of the relationship (2011: 9).*

They further note that positional control is invisibly present in personal control so that in the personal mode 'the visible power relations of the hierarchy are temporarily disguised or masked' (Gamble & Hoadley, 2011: 9) to give the acquirer a wider range of options.

In the foregoing discussion much has been said about social structure and its conditioning influences on human action. Archer (1995) contends however that cultural considerations are just as pertinent in social theorising and that cultural systems also have conditioning influences on agents. These will therefore be the subject of the following section.

2.3 Cultural Considerations

In the previous section social structures were posited which stand in a certain relationship to social interaction. In the same manner, Archer further posits that there is a domain of the cultural which has an objective existence and which is likewise distinct from socio-cultural interaction (Archer, 1998a). A cultural system has elements (such as theories, values, beliefs etc) all of which stand in a certain logical relations to each other. Archer (1996) holds culture to be similar to Popper's World 3 of objective ideas. She notes that these can exist in libraries or in books just as any other accessible resource. In the same way that the structural system emerges from or is at any moment the product of social interaction, so too the cultural system 'is the product of historical socio-cultural interaction, but having emerged … has properties of its own' (Archer, 2000a: 173)

A further claim that Archer makes is that there are causal influences exerted by the cultural system on the socio-cultural level, so that the cultural system has a conditioning influence at the socio-cultural level (Archer, 1988). These causal influences stem from the relations of logic among the elements of components of a cultural system and can be either relations of complementarity or relations of contradiction. As she puts it, 'maintenance of ideas which stand in manifest logical contradiction or complementarity to others, places their holders in different ideational positions. The logical properties of

their theories or beliefs create entirely different situational logics for them' (Archer, 1988: 145).

The working out of these situational logics (or different action contexts) is part of socio-cultural interaction where a variety of situational logics manifest themselves. The relations of contradiction can be either constraining or competitive while the relations of complementarity can be either concomitant or contingent (Archer, 1988: 147 - 170). These are discussed briefly below.

2.3.1 Constraining Contradictions

This category of relations refers to a cultural system that has beliefs A and B, where these are logically inconsistent with each other, i.e. a logical contradiction. This means that the holder of A cannot reasonably also hold B. However in socio-cultural interaction holders of A operate in B's environment, in which invoking A invariably invokes B, which results in the constraining situation. Therefore a constraining situational logic is created where those committed to A have to live with B. Archer stresses however that human actors have the power to evade the situational logic. She further notes that even though they are not determined by it, any action they take to avoid it is determined by the nature of the logic. She proposes that in this type of situation the situational logic generated is that of correction, which seeks to correct the inconsistency. This correction can take one of three forms, namely the correction of B so that it becomes consistent with A, the correction of both so that they are mutually consistent or the correction of A so that it becomes consistent with B. Archer notes that the main thrust of this category at the level of socio-cultural interaction therefore is the sinking of differences which results in ideational unification.

2.3.2 Competitive Contradictions

In this category the propositions are inconsistent and as such cannot be held simultaneously. However unlike in the case of constraining contradictions, invoking A does not invoke B. According to Archer the situational logic created confronts people with

choices; it dictates elimination rather than correction. As she puts it, 'in the former case (i.e. necessary contradictions), actors were driven to cope with ideas that contradicted their own through compromising, conciliating and usually conceding whereas those involved over a competitive contradiction have every incentive to eliminate the opposition' (Archer, 1995: 240).

2.3.3 Concomitant Complementarities

According to Archer, in this category the two beliefs are consistent even though A operates within B's environment. In this case when A is invoked, B is also invoked, which serves to reinforce A. This logical relation also conditions action at the socio-cultural level. In contrast to the description above, however, the situational logic created in this situation is a problem-free one (Archer, 1988). Exploring B is a rewarding experience even for proponents of A, which was not the case in the contradictory relation. Archer notes however that as much as reinforcement may be a desirable consequence of this situation, over time it may lead to closure which insulates the proponents of the system as 'staying inside is cosily inviting … their truths are not challenged only reinforced … they confront no ideational problems … but work according to a situational logic which stimulates nothing beyond cultural embroidery' (1988: 157 - 158). In short, therefore, they work to protect the situation and not to correct it. Archer further notes that the main thrust of this category at the level of socio-cultural interaction, is reproduction and the distribution of similarities.

2.3.4 Contingent Complementarities

Archer defines this category as the 'loosest' of the four. In this category, proponents of A have a choice about whether to hold to it while at the same time being free to think what they will of B. This situational logic makes available a range of different ideas and agents are encouraged to explore congruent ideas or indeed 'to ignore the broader horizon in view' (Archer, 1995: 244). Archer notes that it is free from socio-cultural manipulation designed to induce, in Archer's terms, 'avoidance or adoption or aversion'.

It should be noted, however, that while Archer states that the types of strategic action defined above apply to large sections of the population (as opposed to individual agents), towards cultural and structural reproduction or elaboration as the case might be, it is precisely the process of retroduction that will allow me (by making use of these four categories for instance) to move from an observed event to posit causal mechanisms at the level of the real in order to answer the question 'what does society have to be like for me to have observed what I observed in the teaching and learning contexts of chemical engineering design?'. In this way I am able to make an inferential move from a case that shows the way 'things are done' in chemical engineering education, to explaining enduring pedagogic trends, contradictions and complementarities, in that institution.

The complementarities and contradictions above are types of emergent properties that apply both to cultural and structural conditioning. The descriptions give an indication of how situational logics might be shaped for the agents involved, as well as how strategic action among large sections of the population might be motivated (Archer, 1995). As Archer puts it, 'structural properties (as SEP and CEP)[13], as features of the situations in which people find themselves, can only foster or frustrate projects' (1995: 198). The issue of how segments of the population might organise for strategic action is discussed in the following section.

2.4 Developing a Social Identity

Archer notes that the relations of complementarity or contradiction discussed above give a range of possible strategic moves by a large section of the population. There is an implication here that individuals are able to organise for collective action. Archer addresses this when she talks about the emergence of a social identity (Archer, 2000a). Archer develops the notion of a social identity associated with SEPs and the CEPs in her later works on individual agency and identity (see for example 2000a). These categories are about the mediation of structure by agency. The development of the social identity according to Archer involves three phases providing a stratified ontology of agency:

13 For Archer an SEP is a Structural Emergent Property and a CEP is a Cultural Emergent Property.

1. The development of primary agency (collective agency) – here society impinges on the human self. Primary agency is defined by Archer as involuntary agency, agents who 'are assigned to positions … which means that we become members of collectivities who share the same life-chances' (2000a: 11).
2. The development of corporate agency (collective agency) – here primary agents transform themselves in seeking to transform society through organized groups or movements. According to Archer this transformation depends on the reflexivity of primary agents in seeking to transform society.
3. The development of social actors (individual agency, i.e. a social actor is an individual agent) – here cultural and structural reproduction affect the nature of roles and therefore the social identities available to agents who take up institutional roles as individuals.

According to Archer, movement through these levels of agency takes one to maturity after which there is always a lifelong dialectic relation between the social and the personal identities. Archer notes that agents go through this process in a cyclical manner several times until maturity, so that an agent's personal identity is enriched each time. The process itself is predicated on there being a personal identity.

In her 2003 work Archer outlines a process by which individual human agents have the possibility of mediating the structural and cultural emergent properties. Therefore, arguably before an individual is in any position to engage in collective action, as part of the larger population towards strategic action, they need a personal identity which develops through *reflexivity*. This is described below.

2.5 Mediating Structure and Culture through Agency

According to Archer, her project is to re–introduce human agency into social accounts and to see it co-existing with, reinforcing and being reinforced by structure. She maintains that while structures have the power to shape consciousness, that causal power has to be activated by individual agents (Archer, 2007b). She notes that all people at all times are

confronted with three orders of reality: the *natural*, the *practical* and the *social*. She argues that each of these has its own sets of related concerns. Archer defines *concerns* as '*commitments* constitutive of who we are, which are an expression of our identity' (Archer, 2000a: 4). Emotions (first order) emerge from these *concerns* which mutually affect each other. Our task then becomes to re-evaluate, correct and prioritise our emotions to navigate our way through the three orders simultaneously (Archer, 2000a: 4). This involves decisions about which concerns need to be prioritised and disengaging these from the rest. She argues that this process happens through the *Internal Conversation.* She defines an Internal Conversation as a mental activity that involves silent self-talk that all normal people engage in. She has defined this process as *reflexive deliberation* which involves the following stages (Archer, 2003: 135).

- 'Stage 1: Structural and cultural properties objectively shape the situations that agents confront involuntarily and *inter alia* possess generative powers of constraint and enablement in relation to,
- Stage 2: Subjects' own constellations of *concerns* emerge as subjectively defined by the three orders of reality: *natural, practical and social,*
- Stage 3: Courses of action are produced through the *reflexive deliberations* of subjects who subjectively determine their practical *projects* in relation to their objective circumstances'

Stage 2 of Archer's model is the start of the emergence of first order emotions and the start of the Internal Conversation. This stage represents the interface between the situations subjects face or function under and their projects (actions they embark on).

Stage 3 should then be seen as the conclusion of a particular cycle of the Internal Conversation, meaning that the Internal Conversation culminates in the specification of actions by active agents. Archer (2003) argues that Stage 3 in the three-stage model captures the process of mediation without which there can be no 'explanatory purchase' (2003: 143) on what subjects do. Commitments that emerge at the end of the Internal

Conversation in Stage 2 translate to concrete projects as subjects decide whether they can realise the commitments, adjust them or abandon them in light of their situations. For example, a student who has failed the fourth year engineering design course twice in a row will have to re-evaluate and decide whether she feels she can still realise her ultimate concern of being a chemical engineer. Therefore subjects are interested in those courses of action that they should adopt in order for their ultimate concerns to be realised. Archer further notes that these second order emotions or ultimate concerns are not always stable as everything in the Internal Conversation is temporary.

According to Archer (2003), it is only in the light of actors' personal projects that situations prove to either be constraints or enablements. From this I read that, given a student's express intention of passing a course and getting a degree, certain pedagogic practices in certain courses become either constraining or enabling. In light of this project therefore it is in the student's best interest for the pedagogic practice to be enabling. Furthermore Archer notes that the trajectory from concerns (of self-worth in the social order, of performative competence in the practical order and physical well-being in the natural order) to projects to actual actions is accomplished by reflexive deliberation through the Internal Conversation.

Archer acknowledges that very little is known about the Internal Conversation (Archer, 2003). In a study she conducted in 2003, where she sought to understand how agents mediated structural conditioning, her overall aim was to achieve an understanding of courses of action as determined through the reflexive deliberations of agents. Towards this end she defined four modes of reflexivity: *communicative, autonomous, meta- and fractured reflexives*. These modes were refined in her later work (Archer, 2007b) after further research. She differentiated between them according to the type of Internal Conversation and action, as well as in terms of the relationships each mode has to constraining and enabling conditions. She provided summaries of these (see Archer, 2007a: 1), which are reproduced below. (The underlined emphasis is added for ease of reading).

> *Internal Conversations of communicative reflexives need to be completed and confirmed by others before they lead to action. Further, communicative reflexives remain deeply embedded in their original social context; by* evading *both the objective costs incurred by resisting constraints and also repudiating the objective bonuses associated with enablements, their unit acts serve to reproduce the social structure. Autonomous reflexives tend to sustain complete Internal Conversations with themselves, leading directly to action. They adopt a strategic stance towards constraints and enablements, seeking to avoid society's 'snakes' and to ride its 'ladders' - thus changing their own social position and also modifying the new positions they come to occupy in the pursuit of their concerns.*
>
> *Meta-reflexives tend to be critically reflexive about their own Internal Conversations and socially critical about effective action. They act as society's critics; they are* subversive *towards constraints and enablements because they are willing to pay the price of the former and to forfeit the benefits of the latter, in the attempt to live out their concerns. All of the above are active agents, making different contributions to social stability and change, but also achieving some governance of their own lives in society. Lastly, fractured reflexives are people who cannot conduct a purposeful Internal Conversation, but go round in circles of ever-increasing distress and disorientation. They tend to be passive agents to whom things happen, thus representing a passive force for social stability.*

Archer acknowledges that these are tentative findings but notes that if 'each mode of reflexivity appeared to entail a different stance towards society, then their aggregate effects will make a crucial contribution to social reproduction or transformation at the macro level' (Archer, 2007a: 1).

What should be clear at this stage from the theories of Bernstein and Archer presented is that the pedagogic practices and other structural properties of the society, institution, faculty and/or department provide conditions in which students may or may not be able to infer realisation rules. Whether they do or not depends on the students' projects in relation to their ultimate concerns and the type of reflexivity in which they are able to engage. It is conceivable, however, that the lecturers themselves, as the embodiment of their practices, may be conditioned by particular structural properties which constrain or enable the success of their pedagogic practice.

Finally, analytical separation of the different strata, i.e. of structure and of agency, gives a platform from which the interplay, i.e. socio-cultural interaction, can be investigated without conflation (Archer, 1995). This interplay would have to consider structures and agents as separate strata each possessing emergent properties and powers where structures are the generating mechanisms providing reasons for intentional human

action. The analytical separation of the strata, formally termed *analytical dualism* by Archer, further leads to the idea of the morphogenetic sequence. According to Archer, 'analytical dualism is a method for examining the interplay between these strata; it is analytical because the two are interdependent but it is dualistic because each stratum is held to have its own emergent properties' (Archer, 1995: 133 - 134). Analytical dualism and the morphogenetic approach to which it gives rise are discussed in the next section.

2.6 Analytical Dualism: The Morphogenetic Sequence

According to Archer, past actions predate current actions by contemporary agents and yet condition them in the form of constraints and enablements. These past actions continue to exert their effects on subsequent actors and their activities as autonomous possessors of causal powers. As Archer puts it, 'because the emergent properties of structures, their tendencies, powers and generative mechanisms and the actual experiences of agents are not synchronised, then there will always be a need for a two-part account' (Archer, 1995: 149 - 150). Analytical dualism therefore helps distinguish pre-conditions (emergent consequences of past actions and past agents) from present activities. The morphogenetic approach is designed to operationalise analytical dualism and attempts to theorise how these structural emergent properties and cultural emergent properties exert their effects in time.

This basis of analytical dualism allows for the interplay between structure and agency to be investigated. Bhaskar has called this the point of contact between structure and agency: 'it is clear that the mediating system we need is that of positions (places, functions, rules, duties, rights) occupied (filled, assumed, enacted) by individuals and the practices (activities) in which by virtue of their occupancy of these positions (and *vice versa*) they engage' (Bhaskar, 1989). Archer calls this the practice-position system. She extends the conception of positions to include 'positions in which they find themselves' which might include problematic situations or contexts, but further adds that a position has to exist before it can be filled. According to realism, agency does not create structure but rather transforms or reproduces it in any given generation. The morphogenetic

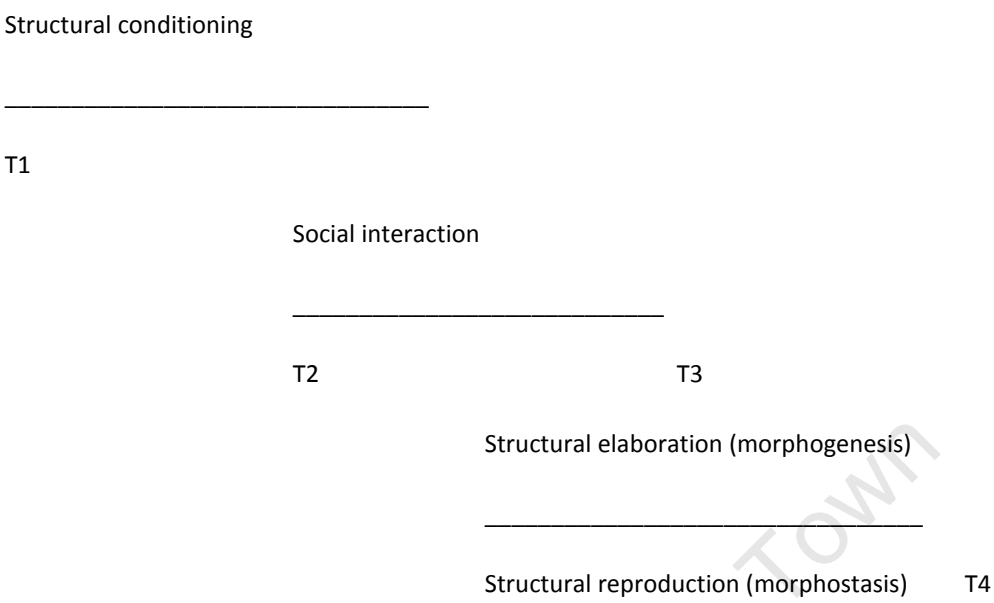
sequence then involves taking the structure and agency flows which are always at work and analytically breaking them into the sequence *emergence-interaction-outcome*. According to Archer (1995: 168), the application of morphogenetic analysis entails four basic propositions.

1. 'there are internal and necessary relations within and between social structures;
2. causal influences are exerted by social structures on social interaction;
3. there are causal relationships between groups and individuals at the level of social interaction;
4. social interaction elaborates upon the composition of social structures'. In other words in social relations agents act back on the structural system thus elaborating it.

According to Archer the first proposition allows statements to be made about social structures without reference to contemporary agents, particularly since social structures are held to be emergent properties whose emergence depends on previous generations. If the relations of the components of an emergent property are internal and necessary, this means that the components cannot exist independently. For example, there are internal and necessary relations between a landlord and a tenant because there cannot be a tenant without a landlord or indeed a student without a lecturer.

Due to the fact that Archer's morphogenetic sequence introduces a time dimension to the analysis, the sequence is divided into time periods (hence the T which represents points in time) which merge in a sequence (hence the numbering). The sequence is represented as a T1 to T4 sequence as is indicated below.

Figure 2: The morphogenetic/stasis sequence (Archer, 1995: 76)



This approach signals the importance of time and history. T1 (the present time) is always conditioned by history and represents how things came to be in the present (Quinn, 2006). It represents the properties of past actions which shape social situations and endow people with particular interests. Action will always be pre-dated by forms of social conditioning. T2 to T3 is an analysis of how agents respond to inherited conditions. It represents social interaction in which agents, whilst socially conditioned, also express their own irreducible emergent powers including intentionality, rationality, personal psychology and reflexivity among others. Archer makes a point of stressing that these powers mean that, whilst agents are socially conditioned, they are never determined. T4 represents elaboration which modifies structural properties in part in line with the intention of actors but in large part in the form of unintended consequences emerging from conflict and concession between different groups (McAnulla, 1998). Agency then does not create structure, but only transforms (or reproduces) it in any generation. T4 of any cycle marks the beginning of another similar cycle with social interaction now conditioned by a modified structural context. However, Archer points out that the stage T4 may very well not be one of structural elaboration (morphogenesis) but social reproduction (morphostasis). Archer (1995) notes that the overlapping horizontal lines

indicate that society is always structured; there is no point at which structures are suspended during interaction while they undergo production.

Archer (1995) further notes that agency leads to structural and cultural elaboration but that agency is itself elaborated in the process (double morphogeneis). This process includes at T1 the socio-cultural conditioning of groups, group interaction at T2 and T3, and then finally group elaboration at T4. This process is said to happen simultaneously alongside structural and cultural morphogenesis. According to Archer, emotions emerge from one's concerns and the two mutually affect each other. The task then becomes to re-evaluate, correct and prioritise our emotions in order to navigate our way through the three orders of reality: the practical, the social and the natural simultaneously.

According to Archer, the task amounts to disengaging ultimate concerns from subordinate ones to reach what she terms *second order emotionality*. As previously noted this process happens through the Internal Conversation. She defines an Internal Conversation as a mental activity that involves silent self-talk that all normal people engage in. The movement from first order to second order emotionality is a shift from the inarticulate to the articulate, from the inadequate to the adequate and from evaluation to transvaluation, where transvaluation entails progressive articulations of our emotions. Archer (2000) represents this as emotional morphogenesis in a T1 to T4 morphogenetic cycle. At T1 prior experience conditions first order emotions. This process is followed by evaluation, articulation and rearticulation (T2 to T3) and lastly the elaboration of second order emotions takes place (T4).

In the foregoing discussion, the morphogenetic sequences of structure and of agency have been presented (the latter not diagrammatically). The morphogenesis of culture is however also implied. Archer (1995) notes that in unifying structure, culture and agency within the same conceptual framework, the relationship between them can be theorised. With respect to structure and culture in particular she notes that the interactional phase of the morphogenetic sequence, whether it be social interaction or socio-cultural interaction, 'entails a great deal of interpenetration between the two' (Archer, 1995:

305). In considering the above therefore, the participants in the study – the lecturers and the students - will be viewed as occupying positions both in the structural and cultural domains simultaneously. This, according to Archer, necessitates theorising of the intersection of the three strata. These issues will be considered in more detail in the discussion once the data has been presented.

2.7 The Research Question

The theoretical concepts developed in this chapter were used in formulating the research question and sub-questions, keeping in mind the issues and rationale raised in the previous chapter, as well as the nature of the questions typically asked in engineering education literature. These are presented below.

How is student success conditioned by social and cultural systems, shaped by social and socio-cultural interaction and mediated by agents' emergent properties in the pedagogic contexts of chemical engineering design?

The related sub-questions are:

a) What structural and cultural emergent properties operate at UCT and in the chemical engineering design context?

b) What are the characteristics of the pedagogic practices in third and fourth year chemical engineering design contexts?

c) What are students' concerns and projects?

d) What are students' views regarding enabling and constraining situations?

e) What modes of reflexivity are available for students, who, although placed similarly at UCT, have nonetheless emerged from different original social contexts?

Chapter 4 will be devoted to sub-question a) and will describe the nature of the structural and cultural conditioning in the situation that students found themselves in at the start of

their formal design education. Chapters 5 to 7 present the socio-cultural interaction over the duration of the third and fourth year courses, and will address sub-questions b) to e).

In answering the main question and using the explanatory framework offered by the critical realist methodology, I will follow processes of description, abduction (redescription or recontextualisation) and retroduction. The specific manner in which the concepts discussed in this chapter are used in the study is discussed in the methodology chapter which follows.

Chapter 3
Methodology

The previous chapter provided detail of the central purpose of this research project, which is to understand the relationship between students and pedagogic structures and how students either as individuals or as collectivities act upon their world in an attempt to bring about favourable outcomes for themselves. These actions are in the context of students' own defined concerns and projects and represent a response to potentially constraining situations.

This study provides a realist account of the phenomena observed with respect to student engagement in chemical engineering design. It is concerned with the relationship between human beings (in the context of a chemical engineering programme) and the social relations that emerge from their interaction. The chapter starts off by giving an account of how the morphogenetic sequence introduced in the previous chapter was used to structure the research design. This is followed by the methods chosen to gather the data which are outlined and justified. Finally the analytical tools are discussed.

In developing an explanatory framework, I will move from description to abduction and then to retroduction. According to Danermark et al. (2002), description is about describing the concrete events and phenomena to be studied using common everyday language. This was done partially in presenting the problem and rationale in Chapter 1. However parts of Chapter 4 (i.e. structural and cultural conditioning) also provide some more detail of the concrete situation under study. Abduction is carried out in Chapter 5 through to Chapter 7 (i.e. an account of the social interaction). This process involves the recontextualising of events and redescribing them using theoretical language (Danermark et al., 2002). Bernstein's theory of pedagogic practice introduced in the previous chapter is used for this. However, other categories emerging from the data are also used as part of the description. Finally, retroduction is conducted in Chapter 8, the discussion. According to Danermark et al. the purpose of retroduction is to ask: 'What is

fundamentally constitutive for the structures and relations (X) as highlighted in stage 2? How is X possible? What properties must exist for X to be what it is? What causal mechanisms are related to X?' (2002: 110).

3.1 The Research Design

The following section provides detail of each phase of the morphogenetic sequence, in particular the concepts used in each phase and their significance in the study.

3.1.1 Structural and Cultural Conditioning (T1)

The situation at T1 was conceptualised as the result of past actions by past actors. It was the result of prior morphogenetic cycles, the result of which was the newly conceptualised third year design project. Broadly speaking, this chapter also presents the institutional situational logics based on the structural and cultural emergent properties of UCT and the faculty. These are positioned as potential conditioning influences on the agents implicated in the study; students as well as lecturers. In this way then, T1 details the cultural and structural milieu of Higher Education Institutions in general, of South African Higher Education Institutions, and of UCT and the Department of Chemical Engineering in particular.

T1 also represents the situation the students confronted at the start of their design education, i.e. half way through third year. To some extent the start of their fourth year, which was the continuation of their design education, is also T1 in that when this group of students started fourth year, the design project at fourth year level had also been redesigned. Therefore, all decisions that were taken by lecturers about how to structure and run design in both third and fourth year were together conceptualised as structural and cultural conditioning. Part of the reason for this choice was that if design is a capstone course, then when students do the design project in fourth year, they draw on third year as well. Therefore these education processes were linked, and part of the interest of the study was to see whether in practice this link was experienced as helpful by the students.

The structures in this situation inhered in the enduring way in which teaching practice is reproduced: lecturers reuse materials in their teaching activities, lecturing notes are passed on from year to year, exam papers get reproduced with slight changes, by and large the same textbooks are prescribed to students and course handouts get reproduced. Other enduring practices conceptualised as structures had to do with management practices with respect to certain functions such as teaching and learning which, although located beyond the department, informed the activities of the department. While these management functions did not necessarily directly impact on students' ability to infer realisation rules in the context of chemical engineering design, the point of the study was to infer a chain of causality with respect to the conditioning influences. It was the enduring nature of these practices and positions, initiated by previous actors, maintained by the activities of current actors which then constituted conditioning structures.

3.1.2 Social and Socio-Cultural Interaction (T2 – T3)

The social interaction phase in this study started in July of one year and concluded in September of the following year. This period covered three semesters; one in third year and two in fourth year. The concepts called on are defined below:

> Lecturer-student relations (the pedagogic relation) – this relation was *a priori* defined as one of internal necessity. This concept captured the relations between lecturers and students and those between them and the pedagogic material resources used. The material resources were the curriculum materials which involved lecturers' activities in delivering the design curriculum and also captured their conceptions of design education which, it is argued, informed their practice. The data gave some idea of whether the result of this interaction modified the properties and powers of student agency. The contexts in which this relation was observed were in lecture theatres (direct observation) and one-on-one student sessions with lecturers (as told to me by the students). The key concepts used to describe this relation were those of classification and framing as defined in the

previous chapter. This section aimed to disentangle ideas as held by particular communities, i.e. lecturers about certain categories of students and students about lecturers in chemical engineering and at UCT from the power relations at the socio-cultural level to then give detail about what was constraining for students.

Student-student relations – again here it was understood that the community of students in chemical engineering held certain ideas and beliefs about certain educational issues relating to chemical engineering (this would be for T1). At this stage however, the point was to understand the power dynamics within the student community, and to see whether there were any power relations at work which disempowered particular students and therefore proved to be constraints for certain categories of students. The idea of emergence suggests that the result of this interaction modifies the properties of each component of the relation. The study showed whether or not this was the case.

Lecturer-lecturer relations – again this relation was not defined as internal and necessary but rather as contingent. But it was left to the data to show whether this was in fact the case and whether, as per emergence, the powers of those involved were affected in any way.

Agency – in all three of the relations described above, the outcome of the social-interaction provided space for agency to emerge. In other words, of interest was what the students were able to do by virtue of social interaction (being in a relation) as opposed to what they could do by virtue of their own properties and powers, in order to realise their concerns. The study thus distinguished primary agency from corporate agency which in turn is distinguished from the positions/ roles taken up by social actors. The modes of reflexivity introduced in the previous chapter will be used to describe individual forms of agency.

Situational imports – these are properties of a situation which become the sources of certain emotions. More specifically, I was interested whether the relations and relations of relations created situational imports for students and how they negotiated these. The trajectory towards action that was of interest was from situations to imports and options available for action.

The first two relations made reference to the ideas held by lecturers about some categories of students as well as those held by other students about their student colleagues. These ideas were in the realm of the cultural system but were not included under T1. Instead it was expected that this information would emerge from the data either directly (verbally said by an interviewee and thus transcribed) or interpreted from an interviewee's statement or even interpreted from an interviewee's statement as reported by another interviewee. What was included in T1 at departmental level were lecturers' ideas and theories concerning curriculum design which informed their decisions regarding the introduction of the integrated design project.

3.1.3 Cultural and Structural Reproduction or Elaboration

Theoretically structural and cultural reproduction or elaboration indicate whether agency (whether demographic or corporate or the effect of social actors in particular roles) has managed to change structure or culture in any way. The main observable phenomenon is the repeated and persistent failure of a certain category of students in the design class. The point was to search for generative mechanism/s existing at different strata, which created the conditions for the manifest phenomena. These structures were posited to have properties and causal efficacy.

The study is longitudinal. This means that the students were followed over a year from third year into fourth year. They were exposed to further design education in the first semester of fourth year which was a different context. Part of the difference was that at the start of fourth year the students were introduced to a different approach to design which was predicated on their third year experience. This process of their design

education and the object of study in this thesis are presented diagrammatically in Table 1 below. For the purposes of confidentiality the actual period of time over which this design education occurred has not been used. Instead Year 1 and Year 2 have been used which represent third year and fourth year respectively.

Table 1: The process of chemical engineering design education

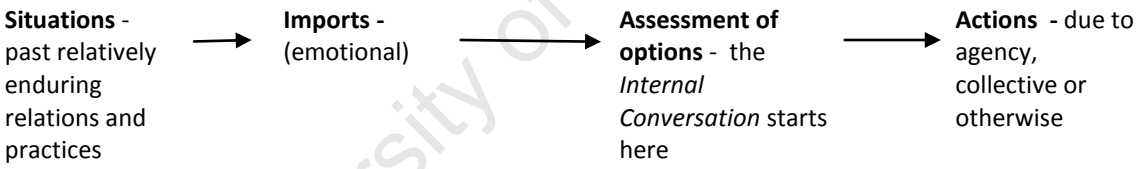
Third year design July (Year 1) to October (Year 1)	**Fourth year first semester February (Year 2) to June (Year 2)**	**Fourth year second semester July (Year 2) to September (Year 2)**
Design approach: basic engineering sciences. First round of seeing how the different courses fit together and are integrated in design.	Design approach: Heuristics (rule of thumb), i.e. design which requires students to make a number of assumptions in the design process in the same way that people with design experience would do.	Design approach: testing competence to practice chemical engineering with some feedback. Here the students are put through their paces. This is the eight week long design project which commences at the end of the 'design education'. Here the students are assessed to see if they are competent in terms of design.

The morphogenetic cycle presented in Figure 2 on page 36 was then superimposed on the table above such that July Year 1 represented T1 and September Year 2 represented T4.

The Third Year Design Project, Process Synthesis and Equipment Design and the Capstone Design Project were conceptualised as a period of interaction. The period of interaction starts in July of Year 1 through to September of Year 2. At the end of T4, according to the approach, there should either have been transformation or stability of the structure as a result of the interaction. The key issue that was considered was whether there was change, and if so, whether it was due to students' demographic agency or corporate agency. At this point data on student agency was also considered, that is, the extent to which they were able to negotiate or mediate the structures in realising their stated concerns and projects. The assumption was that all of them wanted to achieve performative competence in design and that this was their central concern.

An issue that was considered in the interaction phase of the morphogenetic cycle was emotionality. As social beings during the interaction phase, the students were confronted with all three orders of reality. According to Archer, emotions emerge from subject/subject relations, subject/object relations as well as body/environment relations. While the relations that have been charted so far were subject/subject relations, the students in their quest to achieve performative competence also engaged in subject/object relations. The basic thesis then around conditioning situations, emotionality and the realisation of concerns is that, since emotions are commentaries on our concerns (Archer 2000), any situation in which we find ourselves, whether it be of our own making or not, has the potential to threaten those concerns, creating situational imports. My interest was to understand how students mediated these situations, whether as individuals or collectivities, towards realising their main concerns. These concepts and the posited links (i.e. the explanatory theory) are represented below:

Figure 3: Conceptual links



Simply put, prior conditioning creates imports but the relations set up during the social interaction phase also have the potential to create imports. Both potentially affect what the agent sees as his/ her available range of options for action.

3.2 Research Methods

The following section provides details of the external language of description[14] as well as chronological details of my data gathering activities.

14 Bernstein distinguishes between an internal language of description and an external language of description. The former is a conceptual language which only describes itself. Once the internal language is able to describe something other than itself it becomes an external language of description with links to empirical elements (Bernstein, 2000).

3.2.1 Research Setting and Access to Data

I was and continue to be a staff member in the department in which the research was conducted. What this means is that I taught the students whom I was researching when they were in first year and the staff members interviewed are my colleagues. I am a junior member of staff which means the some of the structures that are pertinent to this research predate me. I am also not a regular lecturer in the department but an academic development lecturer. This means that while I am classified as a normal lecturer with teaching and research duties, student learning and engineering education are my key areas of focus. This means that my relationship with the students is slightly different to that of a regular lecturer. When students have queries that do not pertain to academic issues they often come to me. Some senior students (second year onwards) in the department were aware that I was writing a PhD and for some of them this re-categorised me as a senior student. Due to this many students tended to come to talk to me about things ranging from their personal relationships, the hardships of chemical engineering, unfair treatment at the hands of their student colleagues as well as lecturers, and generally confided in me, almost as a counsellor. This was helped by the fact that I had gone through the same chemical engineering degree, a fact known by the students, and hence they assumed that I could sympathise with their concerns. Given my own identity as a black woman, this was particularly the case with black female students. On some occasions I referred the students to the psychologist appointed to the faculty who was better qualified to deal with some of the issues that the students brought to my attention.

As far as my colleagues are concerned, they understand that I have an educational focus to my research and so were quite happy to accommodate my research requests pertaining to their courses. This was largely due to the fact that issues to do with design were of concern to the staff in the department. It was also convenient that I started my study around the time the department was attempting to establish an educational strategy. They were therefore open to providing information that they thought would

help further the department's educational strategy agenda. All the above meant I had uncontested access to the students and the staff concerned in this study.

The uncontested access to students was not entirely unproblematic. During interview situations I needed to maintain a research identity, as opposed to a counsellor identity. In cases where this was not successful I had to steer the conversation to the pertinent issues without 'slipping' into a counsellor role. Coupled with this was the risk of getting too close to some of the issues, having gone through the chemical engineering degree myself, thus creating potential researcher bias. To overcome this I attempted to maintain some objectivity by establishing some distance between myself and the students by not holding conversations about the research with the students outside of the interview situation. My firm intention was not to hold any conversations with the students concerned at all in case this furthered potential researcher bias. This, however, was difficult given my position in the department as an academic mentor.

3.2.2 Purposive Sampling of Lecturers and Students

In order to construct a list of students to approach I used purposive sampling which, according to Lincoln & Guba, 'is intended to maximise the scope of the information obtained' (1985: 274). Since the focus of the study was third year and fourth year, my student participants were the students who were enrolled in the second semester of third year. Furthermore, since the design student failures were traditionally black, the sample needed to include this race category. The students were also chosen based on their school background in order to ensure diversity in this regard. My initial sample size was 19 students. However, two elected to drop out of the project after third year. These were black students, one female and one male. Table 2 presents student information.

Table 2: Student information

Pseudonym	Gender	Population group	Old Education Authority of School	New Education Authority of School	Student GPA[15]	AYOS[16]
Brian	M	White	Cape Education	Western Cape	63.69	2.5
Devon	M	White	Cape Education	Western Cape	76.72	2.5
Gontso	F	Black			65.37	3.5
Kathleen	F	Chinese	Transvaal	Gauteng	63.86	2.5
Katleho	M	Black	DET	Northwest	56.73	3.5
Kelly	F	White	Cape Education	Eastern Cape	73.67	2.5
Mike	M	White	Natal Education	KwaZulu Natal	84.37	2.5
Nandi	F	Black			61.36	3.5
Nazlee	F	Coloured	DECHo:Reps	Western Cape	56.87	3.5
Nolwazi	F	Black	DET		60.03	3.5
Petrus	M	Black		Mpumalanga	61.22	2.5
Tanya	F	Coloured	Cape Education	Northern Cape	69.24	2.5
Tariq	M	Indian	DECHo: Reps	Western Cape	63.58	3.5
Taryn	F	White	Cape Education	Western Cape	73.63	2.5
Tasneem	F	Coloured	DECHo:Reps	Western Cape	56.09	4.5
Thabang	M	Black	DET	Free State	77.06	2.5
Zunaid	M	Indian			60.28	3.5

At the start of the second semester in Year 1 I stood in front of the third year class and told them about my research, what I was doing and why I was doing it. I then told them that I would appreciate their input and that some of them would be receiving emails from me requesting their involvement in the research project. I told them about anonymous research and that they did not need to worry about being identified as I would use pseudonyms. I also told them that I would be attending two of their classes with them for the rest of the semester as part of my data collection exercise. I made this announcement at the start of the first lecture for one of these courses with the lecturer present. A week later I emailed the conveners of the two courses in which I was interested, namely, Reactor Design II and Separation Processes, as well as the Third Year Design Project convenor, requesting to interview them at some point as part of the research. They indicated their consent after which I scheduled interviews with each of them individually.

15 This is the Grade Point Average at the start of YEAR 1.

16 This is the number of years in the programme at the start of YEAR 1

Even though I had twelve black students in the sample, they came from vastly different schools. Among the white group I chose one student who was a high flyer. The other four white students were also relatively successful students, almost all featuring in the dean's list[17]. It was difficult to find a white student who was not performing well among this cohort. I had two coloured students, both females but with different school backgrounds. There were no male coloured students in this cohort. I had two male Indian students, one Indian female student and one Chinese female student. All were South African students. The study did not include international students due to vast differences in the school backgrounds and socio-economic status between this group and South African black students. Furthermore, international students, in particular black international students, tend to perform better than South African black students. I wanted to make sure therefore that the problem of the difference in performance that the study was identifying was not 'diluted' by the presence of international students.

I sent an email message to each individual student telling them what the project was about and asking whether they would be available to participate. Their consent was given through email. Once they had all indicated their consent, I set about organising initial interviews. One of the issues discussed in these first interviews was the issue of anonymity and the use of pseudonyms. Two interview transcripts are included in Appendix B as examples. I also told the respondents that they were welcome to view the transcripts and whatever else I would write about them in order to see how I had represented them in the research.

With regard to the ethics issues relating to the academics in the study, while they were given pseudonyms, it was not possible to completely conceal their identities, even though I had decided in the thesis to obscure the actual years when the data was collected. I thus arranged to make available to them parts of my thesis in which they were implicated. Before doing this however I made sure to omit upfront any data which I viewed to be too

17 According to the EBE faculty handbook the Dean's merit list is published annually and contains the names of students whose academic performance over the year is meritorious and hence worthy of recognition.

damaging. I asked them to comment on whether they felt harmed by the manner in which I had written about them in the thesis. I made it clear to them that the issue was not whether they agreed with my interpretations of the interviews. In their responses, they asked me to rephrase some of my statements or to add details of the context in other places to present what they termed 'an objective view'. These changes were then incorporated in the final thesis.

3.2.3 Data Gathering

Each of the three social interaction periods required a particular type of data collection with specific instruments.

Structural conditioning

For the structural conditioning phase I emailed several lecturers about documentation regarding course contents such as course handouts. I also requested documents generated after key meetings in order to find out what the meetings were about, who were the major decision makers, what decisions were made and whether these were implemented or not and if so the time at which the changes were implemented. The coordinator of the third year design project was interviewed about his rationale for structuring the project as he did. The fourth year lecturers of Process Synthesis and Equipment Design and Chemical Engineering Design were also asked through email about their rationale for structuring their courses in the way they did. In particular the fourth year lecturer was asked to talk about the rationale behind changing Chemical Engineering Design from a pure assessment exercise to a course that incorporated a formative component. Given that design was a course that aimed to bring together all the learning from all other courses in the programme, I also asked him to talk about the idea of starting the integrated fourth year. He then referred me to a colleague of his who responded by emailing me documents.

In all of these questions my intention was to find out about the degree of classification and framing among the courses in the curriculum. In other words, in order to facilitate design pedagogy, what decisions had been made about course content selection and sequencing, the extent of overlap and synchronicity between the courses in the third year as well as in the fourth year. I was looking here to describe the curriculum as planned. All the interviews were semi-structured. This means while there were specific sets of questions, I was happy for the rest of the questions to emerge from lecturers' responses to my initial questions. This meant interview length differed. The lecturers were interviewed only once but email conversations were ongoing, depending on the amount of clarification I required. In the lecturer interviews I wanted to find out whether, given the decisions and structures put in place in order to improve the design education as reported by the lecturers during the data gathering phase, the curriculum as delivered

(i.e. their practices) was able to actualise the ideals reflected in the curriculum documents.

Social interaction

For the social interaction phase I interviewed the third year lecturers for Reactor Design II and Separation Processes. Even though the design project convener was interviewed only once, his responses provided crucial information for both the structural conditioning and the social interaction. I observed practice particularly in third year where the students' design education was initiated, sitting through Reactor Design II and Separation Processes with them. I sat through Process Synthesis and Equipment Design in the first semester of fourth year. I wanted to find out about how the lecturers of Reactors and Separations made design criteria explicit in each of their courses during the semester. I also asked them about their level of involvement in the design project and whether they were in touch with the convenor of the design project at any stage during the semester.

My observation of practice therefore was directed by the concepts of classification and framing introduced in the previous chapter to code the data as indicated in Table 3.

Table 3: External language of description for the level of framing

<table>
<tr><th></th><th>Strong</th><th colspan="2">Weak</th></tr>
<tr><td>Selection – reflected in the course outlines.</td><td>The lecturer was in charge of all contents selected to be covered in the course; students had no say.</td><td colspan="2">The lecturer was not in charge of all contents selected to be covered in the course; students had some say in what was to be covered.</td></tr>
<tr><td>Sequencing – reflected in the course outlines for all the courses involved</td><td>The lecturer was in charge of how the contents followed each other; students had no say in the ordering.</td><td colspan="2">The lecturer was not in charge of how the contents followed onto each other; students had some say in this.</td></tr>
<tr><td>Pacing – reflected in the course outlines by test dates and submission dates.</td><td>The lecturer was fully in control of how long he expected students take to understand the concepts and complete the work. Students had no control over this.</td><td colspan="2">The lecturer was not in control of how long he expected students to take to understand concepts and complete the work. Students had a say in their expected rate of acquisition.</td></tr>
<tr><td rowspan="2">Evaluative criteria – the evaluative criteria were assumed to be embedded in classroom practice, as well as the assessment tasks given and feedback on students’ texts.</td><td rowspan="2">The pedagogy was visible. This means the lecturer specified the requirements for the production of text, told the students what was expected of them, clarified concepts and told them what was missing from their text productions. This was both in the lecturing context and in the evaluation context.</td><td colspan="2">The pedagogy was invisible.</td></tr>
<tr><td>Feedback was given but not helpful. This means the lecturer did not specify the requirements for the production of text, tell the students what was expected of them, clarify concepts and tell them what was missing from their text productions.</td><td>There was no feedback at all. This means the students simply did not receive their texts back (or in time for the feedback to be useful) and were not able to know what was missing from their text production efforts.</td></tr>
</table>

The framing in the positional and personal modes of control were characterised as either weak or strong depending on the lecturer’s conduct and manner in relating to the students. In other words, framing was described as weak if the lecturer allowed students to ask him questions in class without formally requiring them to raise their hands or if he allowed them to walk into his office unannounced to negotiate over aspects of the assessment.

Access to students’ submissions also meant I had another data source for the coding of the framing with respect to evaluation criteria. Some of them were happy for me to keep

their reports while others allowed me to make copies. The lecturer of the Capstone Design Project granted me permission to make copies of the students' final design project submissions.

During the social interaction phase I also interviewed the students. They were interviewed twice each (and some three times) in third year. They were interviewed once in the first semester of fourth year and once again in the second semester of fourth year after the Capstone Design Project (i.e. each student was interviewed at least four times). During the Capstone Design Project I also sat through all the group and individual assessments and orals. These were run by the course convener and I was an observer. My interest there was to see to what extent the convener made evaluative criteria explicit in that context.

The first round of student interviews in third year was based on Archer's notion of reflexive deliberation. An example of an interview prompt is included in Appendix H. This meant I asked the student respondents about their immediate concerns, their ultimate concerns and their projects. I encouraged them to talk about what they considered to be constraining and enabling situations in terms of getting to where they were as well as in their current contexts. We discussed their experience of design, how they were using Reactor Design II and Separation Processes in the design project and whether they preferred to work alone or with peers. In the second interview I asked them to talk about how they were reacting to or dealing with issues they were experiencing during the semester in order to realise their stated concerns which I had established in the first interview. The interviews were also semi-structured and ranged from fifteen minutes to two hours. Further questions emerged from their own responses to my initial set of questions. A sample interview is included in Appendix I.

In fourth year the students were asked about how they experienced design in Process Synthesis and Equipment Design. In particular I wanted to know what was different about design as presented in Process Synthesis and Equipment Design from what they had

previously experienced in third year. This was to elicit any development in their perceptions of what the process of design entailed. I also asked them to talk about how they were dealing with issues in the Process Synthesis and Equipment Design course in order to realise their concerns stated in the previous year. In the second semester I interviewed the students after they had finished the design project. I chose not to interview them during the project for two reasons. Firstly, during this semester the students were primarily putting on performances of understanding with respect to the design, after the two phases of preparation (in third year and in the first semester of fourth year). Therefore, even though I was interested in their perceptions of the context I was also after their 'actual' levels of competence. I had access to these performances as an observer in all the group and individual oral assessments. Secondly, I had access to lecturers' opinions on these performances both verbally through the discussions the lecturers had after each round, as well as through the actual grades and comments on student scripts. In the final interview in fourth year I asked them to give me their perceptions of the design context. Part of this was about hearing their justifications for the quality of performances observed over this period.

3.2.4 Data Analysis

The data was dealt with in two stages. Firstly, given that the primary aim was to understand the structural mechanisms at the level of the real, whose manifestations were at the actual and empirical levels, the stratification of reality model was used to locate the data gathered into the respective levels. To this end, all interview responses were understood as reflecting respondents' perceptions of the context, for both the students and the lecturers, and thus located at the *empirical* level. Students' marks for their submissions were allocated to the *actual*, understood as representing an event. The pedagogic practices representing the pedagogic events and processes that occurred, including the lecturer-student relations, which were characterised using Bernstein's concepts, were also located at the level of the *actual.*

Secondly, I set about analysing the data. The interview questions throughout the entire social interaction phase were geared towards understanding how students deliberated reflexively in order to mediate the structures they encountered when attempting to realise their ultimate concerns. In organising the process of analysis I first re-described the pedagogic practices using the concepts of classification and framing. This was followed by the students' responses to these practices (the social interaction chapters reflect this ordering). In analysing the student response data, I looked firstly at the various emotional responses to the pedagogic practices. I examined students' assessment of options, looking in particular for differences in how they dealt with situations such as a lack of feedback from the lecturer. I verified whether they organised themselves into groups to access other resources, whether they dealt with this individually or whether they did both. This information then gave me clues about students' Internal Conversations and deliberative efforts. The actions which resulted from their assessment of options were also of interest and indeed whether success was achieved or not with respect to the production of appropriate text.

In analysing how students organised into groups I used the student-student relations and in particular what reasons student gave for the groupings they formed. The design project in Year 1 was an individual project and therefore the notion of student groups was different over this time period compared to both semesters in Year 2 where the projects were a combination of group and individual tasks. Finally I looked at whether the assessment of options and the potential power relations at play in the student groupings, for example, created situational imports for certain categories of students, and how these potentially disempowered students as they deliberated over this situation.

In defining students' reflexive deliberations, my point of departure was Archer's modes of reflexivity outlined in Chapter 2, but I adapted these for my purposes, in light of the initial set of data. For the purpose of this study communicative reflexives are those students who are explicit about preferring to work with peers and collaborating but who are also able to turn that collaboration into individual success. Autonomous reflexives are those

students who are explicit about preferring to work on their own and who do what it takes to achieve a desirable outcome on their own terms and are then able to turn that into success. Fractured reflexives can be either autonomous or communicative in assessing options but the action that results does not lead to success.

From this reflexive analysis I was able to say whether some students were doubly disempowered in the social interaction; firstly by the constraining pedagogic practices (which all students were exposed to) but then secondly through the causal influences exerted by the world of ideas (held either by lecturers or other students about their student colleagues) at the socio-cultural level. This gave me an idea about the extent and nature of contradiction that different categories of students lived with as part of their educational experience. The ultimate aim was to understand their deliberative efforts towards achieving success in the design context.

The final stage of analysis consolidated all these findings and retroductive reasoning was used to appeal to social and cultural issues beyond the context of the research to answer the *transcendental*[18] question 'What must reality be like to account for the differences observed?' Here then the level of the real was invoked to provide an explanation about the ways in which institutional and social structures potentially influenced phenomena at the level of the actual. In using the mechanisms at the level of the real to explain phenomena at the actual and the processes at the level of the actual to explain some of the experiences at the level of the empirical, it was assumed that a deliberative gap allowed for agency to occur which accounted for the different responses to some of the prevailing situations.

This analytical framework provided a chain of explanation from which an argument could be made to explain processes and events at the level of the actual as well as experiences at the level of the empirical.

18 Transcendental realism is the idea that it is the nature of objects that provide cognitive possibilities for us, i.e. that allow us to know something about them (Bhaskar, 2008).

A challenging aspect of the data analysis was the interpretive nature of the exercise of analysing interview data. In analysing the data, it is inevitable that I was reinterpreting my subjects' interpretations of their own Internal Conversations. Moreover, because for the final phase of the social interaction the students were reporting their experiences to me based on memory and not actually as they were doing their design projects, I had to accept that some detail would be forgotten and other detail exaggerated. As a result, my analysis was based purely on what was present in the subjects' responses or indeed what was contained in the documents including the transcripts that I had access to. However, I was cautious in this regard not to commit the *epistemic fallacy*, i.e. assuming that what was not said was not real and therefore did not influence the outcomes. The critical issue was to draw conclusions based on the data and from there to use retroduction to infer the properties and powers of structures at the level of the real. The leaps of inference varied in the study and that is perhaps the nature of using the stratification of reality model as a basis for explanation. In the interaction between the actual and empirical strata the observed processes and events were seen to condition the experience of events. However, in order to explain the phenomena observed, and indeed to explain some of the experiences, a larger inferential leap had to be made through retroductive reasoning (Bhaskar, 1989). This allowed me to postulate mechanisms capable of producing the phenomena I observed, mechanisms which themselves were not observable, but whose effects, I argued, were felt.

Chapter 4
Structural and Cultural Conditioning

In relation to Archer's morphogenetic sequence, this chapter focuses on the cultural and structural conditions that characterise the university and the department concerned and which prevailed prior to and led to the introduction of the third year integrated design project in Year 1. The chapter presents some detail about the nature of (chemical) engineering knowledge, with a particular focus on the discourse of chemical engineering design as a cultural emergent property. This latter section presents detail of individual lecturers' ideas about design education, and the structural changes introduced to realise these ideals. Indeed, some of these ideals are held by not just one academic but by a group of them in the department, as will be presented. This chapter therefore does more than present background information. It presents the context of the study from the systemic level (the institutional level) as well as the departmental level. It provides detail of the action contexts (Quinn, 2006) for actors in the socio-cultural level as presented in the following three chapters.

4.1 The Cultural and Structural Landscape of SAHEIs[19]

In writing about the purposes of the university, and about the dominant university discourse, Barnett (2000b) lists the following six themes (which he refers to as constellations) that have traditionally tended to dominate university discourse: knowledge, production, democracy, self, critique and emancipation. Barnett contends that the knowledge constellation, which encompasses truth and reason, has traditionally supplied the framework for the university. Production has traditionally been associated with the economy, work and the vocational; democracy with justice, citizenship and community; self with autonomy and personal development; critique with critical thought and self-reflection and emancipation with liberation.

19 SAHEIs refer South African Higher Education Institutions.

According to Barnett, however, while knowledge, truth and reason have for decades been the traditional university's *raison d'etre,* in the contemporary age, one of *supercomplexity* as he puts it, the university is called to be more. According to Wallace, Schirato & Bright (1999), traditional universities were about improving human beings through reason and theory. For example, Bernstein (1990) talks about the abstract orientation of knowledge in the medieval university due to its Christian base. He notes that this abstract orientation facilitated the idea that God could not only be loved but could also be thought about. Wallace et al. (1999) note that these institutions were created for men in the elite social class preparing them for management roles. The traditional university therefore tended to serve a narrow segment of society and valued certain kinds of knowledge from disciplines such as medicine and law. By serving a narrow segment of society the university maintained autonomy and was not accountable to the broader society within which it was located (Altbach, Berdahl & Gumport, 2005). This autonomy meant the university had the luxury of developing an interest in knowledge for its own sake. Barnett calls this 'disinterested reason', where liberal education was 'free from, untainted by worldly preoccupations' (2000a: 25).

In many ways, therefore, the traditional university was easy to define and the idea of a university was not contested. The university of the twenty first century is however markedly different from the traditional model (Barnett, 2004b). Wallace et al. (1999) attribute this change to the Second World War while Barnett refers to it as the 'postmodern turn' whose proponents assert that 'no large purposes of their own can seriously be entertained by the university and that therefore only instrumental ends are available' (2004b: 61). Regardless of the drivers behind the change, Barnett writes that society is witnessing the transformation of an elite system to a mass system. He identifies other changes that are evident across the world in current times and these include globalization, the interpenetration of higher education with the wider host society, agendas of participation, access and equal opportunity, marketisation of higher education and competition (Barnett, 2004a). The 'end of the university' therefore was/is not due to

the end of knowledge but rather to the proliferation of 'knowledges' which are not all under the control of the university (Barnett, 2000a).

The constellations of production and democracy, with which the modern university associates itself, are associated with work, the economy, social justice, citizenship and community, and among other things 'speak a language of inclusion rather than of exclusion' (Barnett, 2000a: 51). Here then it is evident that the modern university needs to engage with the world or with society, and to be seen to be accountable. Barnett associates the constellations of self with autonomy, personal development and personal realisation; of critique with self-reflection and critical thought and that of emancipation with liberation and freedom. He maintains that these constellations are not unique and that some are implied in others.

In the twenty-first century context some of the values from the traditional university and those of the twenty-first century model have different implications for different parts of the world, largely due to the their particular histories. In South Africa, the Higher Education system was predicated on an agenda of elitism and under apartheid, exclusion. It was

> *Deeply divided internally and isolated from the international community of scholars. It was highly fragmented in structural and governance terms and was far from being a coherent and coordinated … It was inherently inequitable, differentiated along the lines of race and ethnicity, and designed to reproduce the white and male privilege and black female subordination in all spheres of society (Badat, 2003: 13 cited in Council on Higher Education 2004)*[20].

This fragmentation of the Higher Education system in South Africa made it difficult to talk of a unified Higher Education system in the country (Council on Higher Education, 2004). Historically white universities (both English and Afrikaans medium) enjoyed considerable autonomy from the state, the English (or liberal) universities in particular due to their

20 The CHE is The South African Council on Higher Education, an independent statutory body responsible for advising the Minister of Higher Education and Training on all higher education policy issues, and for quality assurance in higher education and training. This report, published as it was after ten years of democracy, describes and analyses contemporary conditions within South African higher education and the changes that have occurred during the past decade, with particular reference to the inherited situation in 1994 (Council on Higher Education, 2004: i) .

opposition of the apartheid policies at the time (Hall, Symes & Luescher, 2002). As was the case in the traditional university, albeit for somewhat different reasons, under apartheid, the South African Higher Education system served the minority.

From 1990 onwards several transformational initiatives were put in place. Their main aim was to reintegrate the Higher Education system in South Africa (Hall et al., 2002), with the concern being equity of access for all citizens. According to the CHE, 'higher education … a vital social domain and activity in general, and specifically in relation to the reconstruction and transformation agenda in South Africa' (Council on Higher Education, 2004: i).

From this point it was clear that South African HEIs were seen as instrumental in 'contributing towards consolidating democracy and social justice, producing critical intellectuals, developing knowledge, and expanding and improving the economy' (Council on Higher Education, 2004: 16). Therefore while it is clear that the South African Higher Education system embraces the constellations Barnett refers to, the ideals of democracy (with all its associated concepts) and emancipation have a special place in SA, due to the history of the country.

Some structures in Higher Education Institutions arose or are in place in an effort to realise some of the ideals mentioned above. As Archer warns however

> *Certainly some material relations may and frequently are legitimated by reference to ideas, but the two should not be elided, for a material relationship can be sustained by coercion and manipulation, thus its legitimation is not a matter of necessity (1995: 175).*

Further, the ideas and values mentioned above all stand in relation not only to each other but also to the manner in which these are actualized structurally and ultimately experienced as the social interaction level.

The Council on Higher Education (CHE) (2004) report details a number of areas that were a key focus as part of the post-1994 restructuring initiatives. For each of these areas the report details the inherited situation prior to 1994, as well as the situation after ten years

of democracy (Council on Higher Education, 2004). Out of this list of eleven, three have been identified as the most pertinent to this study. These are:

- Equity (e.g. addressing issues of staff and student equity as well as access)
- Teaching and learning (e.g. addressing curriculum restructuring)
- Research (e.g. Higher Education responsiveness to national goals and research output).

Given the concern in this study with the sustained poor success rates of black students in chemical engineering design, issues of equity, teaching and learning and research are of particular importance.

4.1.1 The Twin Imperatives – Teaching and Research

According to the CHE report, policy requires HEIs to generate new curricula and models of teaching and learning to accommodate a larger and more diverse student population (Council on Higher Education, 2004). Moreover, Higher Education is expected at the same time to deliver research, highly trained graduates and the knowledge to equip society with the capacity to address national needs (see White Paper 3 1997). What is captured here then are the twin imperatives of HEIs: teaching and learning on the one hand and research on the other. When examined closely however, it can be argued that these twin imperatives of HEIs are in fact the responsibilities of the individual lecturers.

According to Rowland, Byron, Furedi, Padfield & Smyth (1998), a false dichotomy has been created between teaching and research, a situation which has been exacerbated by the different funding arrangements for each of these. As they state, 'universities are places for learning. As academic workers in universities, our business is learning: our students' learning, our own learning, our society's learning' (Rowland et al., 1998: 133). He further notes that while teaching and research define the academic role, the two categories are not adequate for distinguishing between different aspects of an academic's role (Rowland, 1996). Nonetheless this dichotomy reflects a global trend in higher

education in which teaching is pitted against research thus creating a situational logic of tension for academics.

4.1.2 Equity, Teaching and Learning, Academic Development

The CHE report noted that while there were improvements in the enrolments of previously marginalized groups after ten years of democracy, what remained a challenge was the balancing of equity and quality. 'Equity of opportunity and outcomes will crucially depend on high quality provision in teaching and learning, curriculum innovation and appropriate academic development and mentoring initiatives' (2004: 90). The report further notes that attention will need to be paid to Science, Engineering and Technology (SET) enrolments to bring these in line with national targets and thus ensure responsiveness to economic development needs.

The report also noted that teaching and learning practices and the curriculum in the apartheid regime were as fragmented as the institutional structure in which they were located. English language universities were dominated by western academic practice, which did not change to accommodate the intake of black students in the 1980s (Council on Higher Education, 2004). While mainstream provision did not change, 'academic development programmes with extended curricula for educationally disadvantaged students began to feature' (2004: 94). The curriculum in Afrikaans language universities was constructed around the idea of the *volks*[21] university. Thus, the idea of a university as autonomous was rejected and instead 'conformity of belief and intellectual rationalization of the apartheid society' were favoured (2004: 94). The report further notes that curriculum in historically Black universities was a 'watered-down version of education in Afrikaans-language Higher Education Institutions' (2004: 94) with the purpose of suppressing student political consciousness.

21 This word has origins in German and refers to 'nation' or 'a people' in the ethnic sense. It has been used in South Africa by an Afrikaans minority wishing to establish an independent, autonomous and self-governed Afrikaans speaking state, i.e. a Volkstaat.

When transformational initiatives were initiated in the 1990s, the focus was on national policy frameworks and institutional responses to the disciplinary and interdisciplinary nature of learning programmes, the outcomes of learning programmes and articulation between qualifications (Council on Higher Education, 2004). According to the Education White Paper (1997) foundation programmes were also to play a significant role in terms of providing access to higher education for previously marginalized groups. Such programmes, according to the White Paper 'will be given due weight and status as integral elements of a higher education system committed to redress and to improving the quality of learning and teaching' (1997: 2.34).

4.2 Structural Landscape of UCT

The ideals of access, equity, inclusion, and increased participation taken up by South African Higher Education Institutions in general, and by UCT in specific, have given rise to a number of structural properties both at the institutional level and by association at the departmental level.

UCT is a 'historically white liberal (English medium) university'. In its mission statement and its statement of values it defines its identity as *research-led*. According to this statement this identity is shaped by a commitment to academic freedom, research-led teaching and learning and community involvement, advancing and disseminating research that addresses the issues facing society and protecting curiosity driven research (University of Cape Town, 2001: 1). The statement also mentions the specific intention to promote diversity and transformation in the institution. Therefore while this university does embrace some of the traditional ideals already mentioned, as is evidenced for example by the commitment to protect curiosity-driven research, there is at least a stated recognition that it is positioned in a specific country and local community which has a specific history.

Academic freedom, also one of the key values of the traditional university, is also endorsed by this university. The notion of academic freedom is not a simple concept but

one that exists at all levels from the systemic to the individual academic (Hall et al., 2002). According to the White Paper the principle of academic freedom implies

> *The absence of outside interference, censure or obstacles in the pursuit and practice of academic work. It is a precondition for critical, experimental and creative thought and therefore for the advancement of intellectual inquiry and knowledge. Academic freedom and scientific inquiry are fundamental rights protected by the Constitution (1997: 14).*

There is also a declared commitment to providing inspired and dedicated teaching and learning, to promoting a more equitable non-racial society and to supporting redress of past injustices.

4.3 The Cultural and Structural Landscape of the EBE Faculty

The ideals presented thus far have been adopted by the Faculty of Engineering and Built Environment (EBE) in which the Chemical Engineering Department resides. The faculty has taken up the issue of widening access and academic development. This issue concerns admissions strategies and academic development for students from disadvantaged backgrounds. This is a pertinent issue in this study given that some of the students in the sample are from disadvantaged backgrounds and again that some of these gained entry into the programme by enrolling for the academic support programme in engineering. Some of these students would have also been 'the beneficiaries' of alternative admissions systems as practiced by the faculty and department involved.

The Handbook of the EBE (2010) faculty contains a Teaching and Learning Charter[22] which stipulates the responsibilities of both students and lecturers (termed teachers in this document). The responsibilities of lecturers included below are to

- provide clearly written course outlines, setting out what is expected of students for the complete course, that are available well in advance of the beginning of the course, to allow students adequate time to prepare;
- provide lists of required and recommended reading for courses, in advance of the beginning of the course, and to establish that this material is in the

22 This is a University document distributed to faculties.

University Library, in local bookshops (by timeous submission of reading lists), or in course readers (with copyright clearance, and within agreed policy for course levies);

- set out a clear and well designed system of assessment for the course, which defines what is expected of a student, and the relative value of different coursework, test and examination components; set clear and consistent DP requirements for courses, consistently enforced;
- present lectures and tutorials in a clear manner, explaining technical terms where appropriate;
- establish a fair and consistent approach to hearing requests for concessions and re-marking of assignments, and for leave of absence from lectures (where attendance is compulsory), tutorials and other class sessions;
- adhere to an agreed and published timetable for lectures, tutorials and other teaching sessions, that respects the need of students to plan their class attendance and study time;
- ensure that they, and other teaching staff involved in their courses, are available to meet with students at advertised office hours, and interact with students without discrimination or favouritism;
- return work submitted for assessment within a reasonable period of time, with adequate and appropriate comments and other forms of evaluation, and ahead of formal examinations, so that students can incorporate feedback in their examination preparation;
- ensure consistent marking of examination papers and, for large classes, effective moderation of examination marking by the lecturer concerned;
- organise a written evaluation for each course, allowing students to express their views freely and, if they wish, anonymously, and build on the outcomes of such evaluations in adapting the course for the future (Faculty of Engineering and the Built Environment, 2010: ii).

According to the handbook this list provides guidelines to inform the academic practice of lecturers. The handbook further declares that these codes of practice are not designed to be prescriptive but rather provide a baseline for professionalism, and concludes that

while heads of academic departments are responsible for teaching and learning at Senate level, individual academic staff members 'are accountable for their contribution to the university's education mission' (2010: ii).

This teaching and learning charter states that ultimately it is up to the individual lecturer to contribute to the university's educational mission. Arguably however, the only means by which the department, indeed the institution, has of knowing how individual academics 'perform' in their teaching and learning endeavours is through the course evaluation structure. This is a forum for students to 'voice' their opinions on the quality of teaching received for a specific course.

Further, an individual academic's progress in terms of the contribution made to research is most significant for the academic in terms of performance appraisal and promotion structures. At UCT the performance process is termed 'rate for job', and is a record of an academic's contribution in a number of areas, two of which are teaching and learning and the other research. UCT's research-led identity means that while teaching and learning, social responsiveness, administration and other areas are noted as part of an academic's duties in the academy, what is most significant for the individual's personal development, promotion and advancement is their contribution to the institution's research agenda. This is of course common in all research-intensive institutions around the world.

The Department of Chemical Engineering (which resides in the EBE faculty) in its mission statement declares its commitment to maintaining a working environment where diversity and creativity are encouraged. In many ways the department has a history of valuing teaching and learning and in particular educational development. It was the first in the faculty to include among its academic staff members an education practitioner, whose brief at the time was educational development, with a title of Educational Development Officer (EDO). A second education practitioner was appointed several years later, termed an Academic Development Lecturer (ADL). At this time, the department pioneered a successful student mentoring programme for first year students

administered by the ADL but run by senior students in recognition of student problems in the first year of university.

The EDO was also for a period the director of the Centre for Research in Engineering Education (CREE), a unit formed 'to establish and promote engineering education as a research field both at UCT and in the broader academic community' (CREE, 1996: 1). One of its objectives is to 'promote research that informs the development of the learning environment and educational process in engineering, science and related disciplines, in order to improve student learning and graduation rates, with specific reference to issues of race, gender and disadvantage' (CREE, 1996). The EDO played a leading role in education research activities in the department, one of six active research areas. She spear-headed the department's educational endeavours with support from senior members of staff.

The department prides itself on its commitment to engineering education. This is reflected in statements such as the following (adapted from Department of Chemical Engineering, 2010):

> *The Department of Chemical Engineering is, above all, a centre for teaching and learning. Education comes first. Our open door policy combines with personalised academic counselling….and an ongoing process of curriculum review. The importance we place on constructive relationships pervades all aspects of the programme. Students work individually, in pairs and in groups, a practice that breaks down barriers and engenders a co-operative approach to problem solving so vital to success in life. Similarly, academics work in teams to teach courses, conduct research and devise new approaches to teaching.*

The department itself, as previously mentioned, has a culture of reviewing their engineering education practice as evidenced by the frequency of meetings directed specifically towards engineering education. The latest curriculum review has culminated in a proposed 'new curriculum' which is due to be 'rolled out' in 2013. The current curriculum originated in 1995 and has been modified since then to its current form. According to a document released by the department, while the outcomes of the educational process were being viewed favourably by the employers of the department's

graduates, there were still problems with the curriculum. The following problems were highlighted (Department of Chemical Engineering, 2008).

1. The current curriculum is currently unbalanced with a heavy course load in 3rd year.
2. The current curriculum is rigid in its structure leaving little flexibility for the students to choose.
3. Students experience the curriculum as overloaded, which does not allow sufficient time for assimilation of knowledge.
4. Assessment in the current curriculum does not formally separate between basic chemical engineering and advanced chemical engineering. In the current curriculum it is possible to pass courses without a sound basic understanding. Hence, basic knowledge should be clearly defined and should be assessed on its own.
5. Some aspects in our curriculum are not taught in an order which allows the students to develop systematic thinking.
6. The vertical integration of the curriculum requires continuous attention.
7. The current curriculum is hardly in line with the mission of UCT to be research-led. From a strong research department, such as ours, a stronger exposure of our undergraduate students is desirable. This would ensure that students are taught using material, which is relevant (if research in the department stays relevant) and by experts in the field.
8. The current curriculum must be adapted to prepare graduates for challenges of the 21st century.

In the same document it is noted that

> *A chemical engineering curriculum should have as a primary outcome graduates who have an understanding of basic science and basic chemical engineering principles and can apply this understanding in an integrated manner. Hence, building competency in design (possibly in a wider sense as currently used) should be a thread throughout the curriculum (2008: 1).*

This document provides a sense of the concerns that drive the department's constant preoccupation with their engineering education practice. Moreover, the issues raised which have fuelled the curriculum review are issues largely concerned with student learning, or more appropriately, they are academic's ideas and beliefs about what the educational process and experience should be for undergraduate students.

Other changes that have taken place concerned chemical engineering design education. Unlike the changes envisaged for the 'new curriculum' however - the development of which involved months of planning and involved a 'task team' who convened regular

meetings in consultation with the rest of the academic staff - the changes to chemical engineering design education were not necessarily conceptualised in the same manner. Rather, these were taken on by individual academics that were concerned about specific issues around their courses and design education, and set out to bring change. These are discussed in due course. Before that discussion however, the issue of chemical engineering as a discipline, the knowledge of design and related issues are discussed.

4.4 Chemical Engineering

The following discussion is about the nature of the discipline; its history in terms of the ideas and opinions that formed the contemporary curriculum and indeed the nature of the knowledge (chemical engineering design knowledge) that it is this department's function to 'disseminate'. This will then be followed by specific structural (curriculum and pedagogic) innovations that were put in place by the department in order to realise the ideals and beliefs.

4.4.1 The Discipline, the Values, the History

According to Clark, universities are a collection of disciplines which 'import and implant the orientations to knowledge' (1983: 31). They view disciplines as the major structuring principle for knowledge. Young & Muller (2010) conceptualize disciplines in terms of boundaries in relation to knowledge. The links between knowledge and disciplines have been widely written about (see for example Ball, 1990; Bernstein, 2000). Bernstein does not refer to them as disciplines but instead as singulars and regions. He notes that singulars (such as the sciences) produce discourses that are only about themselves with no external referents, while regions (such as engineering) are created by recontextualising singulars. He then talks about knowledge structures which he links to disciplines. He distinguishes between a *hierarchical knowledge structure* which is 'a coherent, explicit and systematically principled structure, hierarchically organised' which 'attempts to create very general propositions and theories, which integrate knowledge at lower levels, and in this way shows underlying uniformities across an expanding range of

apparently different phenomena' (1999: 161 - 162), such as physics, and a *horizontal knowledge structure* which is defined as 'a series of specialised languages with specialised modes of interrogation and criteria for the construction and circulation of texts' (1999: 162), such as each of the disciplines of the humanities and social sciences.

While Becher & Trowler (2001) argue that it is not always clear how to define disciplines, they contend that disciplines may be conceived of as having recognizable identities and cultural attributes. Jolly & Radcliffe (2000)view disciplines as 'hegemonies of meaning and practice' (Jolly & Radcliffe, 2000: 357). They further add that such a system of organization may 'predispose consent to and compliance with the status quo…' (2000: 357). They contend that disciplinary orientations in terms of content and procedures are hegemonic in that they provide taken for granted frameworks within which practitioners work. The point they make is that while these orientations are always contestable, they persist and change from the norm is always slow.

Jolly and Radcliffe (2000) talk about the meanings and values that sustain the discipline of engineering. Some of these include positivist approaches to knowledge and a high degree of individual competitiveness. They further argue that engineers tend to be concerned with order and certainty, are averse to ambiguity, have a rather narrow range of interests, and are not given to introspection. The sentiments regarding positivist approaches to knowledge in particular are echoed by Johnson, Lee & McGregor (1996) who lament the 'captivity' of engineering to the discourse of science. They attribute this to the popular view that engineering is based on scientific principles. According to them, while true, it has meant that 'while engineering teaching and scholarship have remained closely connected with the academic disciplines of science, to a large extent they have remained isolated from the pragmatics of engineering as a professional practice' (1996: 20).

Quinn (2006) notes however that in the modern university the idea of a discipline is being challenged by the pressure for academics to look for social and economic relevance

rather than intrinsic disciplinary values. This discourse of relevance goes hand in hand with that of generic skills, inter-disciplinary values and the move from knowledge to 'knowing' (Barnett, 2000a). Quinn further notes that this move has affected some disciplines more than others. The sciences and humanities faculties were the most affected whereas the 'professional and vocational faculties have been less affected because in most cases curricula were designed to meet the requirements of specific professional and industrial bodies and were oriented towards work' (2006: 135).

Chemical engineering emerged in the late nineteenth century during the industrial revolution which signaled an unprecedented need for the efficient production of bulk industrial chemicals (Furter, 1982). Up to this point, chemicals had been produced mostly in batch mode, largely for what were considered expensive products. The discipline thus emerged as a merger of industrial chemistry and mechanical engineering. At this time, chemical engineering was not as easily distinguishable to the lay-person as other engineering disciplines (Hougen, 1977). For instance, mechanical engineering was associated with machines, electrical engineering with circuitry, and civil engineering with structures. What was to set chemical engineering apart was the shift in the approach to the design and analysis from a product or a process to processes. This signaled the birth of 'unit operations', which emphasized the unity among seemingly different operations.

There are varied accounts as to the development of the *unit operations* approach to chemical engineering education. Academic chemical engineering was taught in universities around the 1880s, both in Europe and in America (Cohen, 1996). At that time, in England in particular, it amounted to what Cohen refers to as 'a plant manufacturer's catalogue' and practicing engineers used them to select pieces of plant equipment that best suited clients' needs. This descriptive handbook had detail about different plant equipment and the author, George E. Davis, was credited with coining the term unit operations. At about the same time in a London college, a chemical engineering course leading to a diploma in chemical engineering was developed that prepared students for technical teaching posts, for engineering positions as well as for management positions

(Cohen, 1996). It was part of a chemistry department however and the name 'chemical engineering' was soon changed to 'chemical department'.

According to Donnelly (1986), reintegration back to the chemistry department was due to the differing values regarding what courses needed to be prioritised. The appointed chair of the department, Armstrong, favoured pure chemistry but the council who appointed him wanted an industrially orientated course. This, according to Cohen, created further conflict regarding the orientations of academic chemical engineering. Those who preferred the 'scientific method', such as Armstrong, also preferred the more fundamental approach to chemical engineering 'in which the design of a chemical plant would be based on fundamental scientific analysis of the chemical and physical processes involved' (Cohen, 1996: 177), as opposed to the applied research approach (the unit operations approach) then termed 'engineering-science' (as opposed to pure science). Armstrong's graduates, graduates schooled in the pure science approach to chemical engineering, were not attractive to employers at that time (Weale, 1985). They were seen to not have the expertise required by industry.

After a period of 'to-ing and fro-ing', aspects of chemical engineering design were taught to chemistry graduates (in departments named *chemical technology*) in colleges of science. Cohen notes that at the College of Science in London, the chemical technology department had a strong industrial orientation. The lecturer, Hinchley, who took up the course, had industrial experience and was also at the time working as a consultant in the design of chemical plant units. Cohen describes the evolution of Hinchley's course

> *From relatively rudimentary design work based on a limited experience and data, towards a situation where scientific analysis is combined with experimental data…I am convinced that Hinchley was working at an altogether different level from Davis who, a generation earlier, had described in a merely qualitative way the appropriate use of the various units of plant available to the chemical manufacturer (1996: 180).*

While the account described above referred to the situation in England, there were similarities in the United States. Chemical engineering was first taught in chemistry schools; the lecturers who taught chemical engineering were educated in Germany and as

such had a strong focus in industrial chemistry. The proponents of the unit operations approach noted that 'only a thorough familiarity with industrial problems … would teach students when and how to apply scientific theory … a much smaller matter to both teach and learn pure science than … to intelligently apply science to the solutions of problems as they arise in daily life' (Servos, 1980: 532). According to Cohen (1996) the fact that there were a small number of processes called unit operations and that they found practical application in a wide variety of industrial and research situations made the concept an excellent teaching tool.

According to Cohen (1996) the dominance of unit operations in engineering education was eventually challenged after the publication of a text called Transport Phenomena in 1960. The authors' motivation was that chemical engineering education needed to emphasise the understanding of basic physical principles, which signaled a shift to the scientific focus. Despite this view they didn't completely abandon some techniques that were based on unit operations. According to Griskey (2002), part of this change was due to that fact that educators recognised that unit operations were composed of a subset of transport process.

The discussion now turns to the specific issue of design, in particular chemical engineering design.

4.4.2 Chemical Engineering Design Education

Chemical engineering design, as is taught in the final year of the chemical engineering curriculum, evolved from the combined unit operations and transport process approaches. In other words, it is the culmination of the engineering science and the pure science approaches, both of which are acknowledged as important in contemporary chemical engineering education. Of design in general, Turnbull says that 'While engineers engage in a range of activities, it is design that lies at the core of the discipline. Technology development and application are driven by the demands of engineering design' (2007: introduction).

He advocates that the conception and design of systems are the fundamentals of engineering. If this is the case then it seems design education needs to be one of the most important curriculum issues in engineering education in the twenty-first century. According to Pearce (2002), in a university department students need to be given the opportunity to practice design by working on realistic projects in multi-disciplinary teams. He maintains that it is important that students understand how theoretical constructs are applicable in practice. According to Wallace (2005b), teaching design is not the same as teaching engineering science. He argues that the former is about synthesis while the latter is about analysis. Despite this difference he contends that the two need to be seen as partners and that ultimately a design course needs to give students the confidence to apply their knowledge of the fundamental engineering science to analyse and evaluate design concepts.

The notion of what design and design education needs to be, along with thoughts on issues that students struggle with in design (as opposed to other engineering science courses) has resulted in some structuring or revamping of curricula to enhance design education. In Wallace's (2005b: 12) case, he identifies the following issues that students struggle with in design:

- developing their own analytical models
- realising that there is no 'correct' solution
- appreciating the iterative nature of design
- visualising in three dimensions (3-D)
- communicating with limited engineering vocabulary
- paying attention to detail
- coping with incomplete information
- coping with their lack of technological repertoire and knowledge of existing solutions.

The Department of Chemical Engineering at UCT had their own issues of concern that resulted in structural changes to their design education. Some of these have already been alluded to but more detail follows. The changes happened both in the third and fourth year of the chemical engineering curriculum and will be described in that order.

4.5 Structural Changes to the Design Education

The following section provides detail of the changes to the provision of design education that were implemented in the Department of Chemical Engineering in each of the three periods of interest.

4.5.1 The Changes in the Second Semester of Third Year

Prior to the introduction of the integrated third year design project, each of two core courses in the second semester, Reactor Design II and Separation Processes, had its own design project. In both courses unit operations were designed as isolated units. According to Prof Reed, one of the senior academics in the department, the introduction of the design projects in the third year dates as far back as the mid-nineties. Several years later he modified his approach to the teaching of reactor design by introducing a recycle loop.

> *In the course Reactors, I moved closer towards designing the reactor in the context of a process loop, i.e. including recycle … the rationale behind this was that the reactor and the separator are not designed in isolation, but both pieces of equipment can put constraints on the design.*
>
> *(Prof Reed, Email communication)*

This extract reflects Prof Reed's beliefs about the role of unit operations in design. This approach was an attempt at moving towards an integrated reactor design but was still only about the reactor. The idea of the integrated design was further elaborated on in 2003 when the combined reactor and separator design was introduced. The integrated model of 2003 was further modified in Year 1 of this study. The significant change was that Prof Strauss took over from Prof Reed at the start of Year 1 and introduced tight controls on the administration of the project. This meant he wanted to move away from merely giving the project brief at the start of the second semester in third year and then 'letting the students loose'. The new model had some key differences with respect to the

pedagogic practice intended to deliver the discourse. Prof Strauss talks about this difference in the following extract.

> *In the past we set a list of tasks and we said go 'do it' and 'what happens if people do it in the last week?' … so we've actually given them a breakdown of parts and when to hand it in…*
> *(Prof Strauss, Interview)*

He wanted to make sure that students engaged with the task and made proper use of the time they had by structuring the submission dates. His insights about introducing the design project in third year were gleaned from his involvement in the fourth year design project. His intentions were therefore to model a certain way of thinking about and approaching the design building on basic engineering

He also talks about what would cause a student to fail in third year design and what would fail them in a fourth year design project:

> *If you can design and can put the pieces correctly and that's all you've done, it's a pass in third year. It's a fail in fourth year but it's a pass in third year.* *(Prof Strauss, Interview)*

It would seem therefore that the introduction of the integrated third year design project was done to make more explicit to the students prior to the high stakes design environment of fourth year the fundamental processes necessary to create a basic design, as well as how to move from a basic design to create an integrated whole where the bigger picture has been taken into consideration. In further deciding about the new model of the integrated design project, it was decided by Prof Strauss that the marks obtained in the design project would contribute to the class marks of Reactors and Separations. It was decided that the project would contribute twenty percent towards the Reactors final mark and fifteen percent towards the Separations final mark. The Separations course further required that the students obtain a minimum mark of forty percent for the design project while no such mark restrictions were in place for Reactors. This meant a student achieving below forty percent for the project would automatically lose their duly performed certificate for Separations and would therefore not be able to

sit for the Separations final examination but would still be able to sit for the Reactors examination.

It would appear therefore that prior to the introduction of the third year design project in Year 1, there was no *structured* way to transmit the design discourse. Integrated design pedagogy did not really exist in the department in third year which meant students had to grapple with the rigours of design in the high stakes design environment in fourth year. After seeing the negative implications of students dealing with the rigours of design in the fourth year, Prof Strauss and colleagues grappled with the issue and that culminated in the introduction of the integrated and more structured third year design project. The lecturers were concerned that students were missing some key skills and introduced a structured project in third year which was meant to explicitly teach the design process.

The academic member of staff in charge of Separation Processes was lecturing the course for the first time during Year 1. Dr Smith had been lecturing on the Reactor Design II course for a number of years as it was his area of expertise. Prof Strauss had previously lectured on both these courses for a number of years.

4.5.2 The Changes in First Semester of Fourth Year

The first phase of the students' design education therefore presented an approach to design where students were required to work from engineering science principles in order to design specific units, and to then create an optimised process flowsheet which included two major pieces of equipment, namely a reactor and a separator. This second phase of their design education placed more emphasis on design philosophy and provided a more global view of process systems. Here students were required to work with a larger system and to go beyond just the reactor and the separator as key components of a flowsheet.

Moreover, in third year the students' design education was limited to the design project in third year. This meant that while the students were expected to draw on the

knowledge from the other third year courses, the lecturers of those courses were not necessarily lecturing with the design project in mind.

According to the Process Synthesis and Equipment Design course handout, 'the course aims to familiarize students with the design of entire chemical processes, building on but going beyond the sizing of major equipment as learnt in third year, and minor equipment, pipe work and heat exchangers as learnt in second year' (2009b: 3). This macro approach to the design set this course apart from the design the students had done in third year. The main aim of the course, according to Mr McAvoy, who had been lecturing on the course for the last eight years, was to serve as preparation for the final year design project run in the second semester of fourth year:

> *Basically, Process Synthesis and Equipment Design is a trial course for Chemical Engineering Design. The course is designed to give the students an experience of what the design project will be like… So many students were not passing design and the Process Synthesis and Equipment Design course was conceived to improve the student's preparation for design.*
>
> *(Mr McAvoy, Email communication)*

From this extract, Process Synthesis and Equipment Design was about preparing fourth year students for the final second semester design project in order to improve the pass rates.

The idea of having a fourth year first semester course that prepares students for the rigours of the final design project dates back a number of years. Up until eight years prior to Year 1, students were introduced to the final design topic in two separate projects: a business project and a safety health and environment project. Ten years prior to Year 1 the programme committee for the chemical engineering course and the teaching staff of the department submitted a proposal for changes to the curriculum in the first semester of fourth year. The proposal was for an integrated first semester as opposed to the non-integrated model that was in place at the time. Several reasons motivated the change. It was felt that the contents in the business course spanned topics which 'in a classic design hierarchy precede and follow those that are taught in the process synthesis course' (Department of Chemical Engineering: 1). Secondly, it was felt that students performed

poorly in the cognate engineering courses which formed a third of examinable material in the business course. Further, some of the cognate engineering topics were related closely to material covered in the process control course. Finally it was felt that while it was desirable to move towards a system where students were examined by projects as opposed to traditional examinations, the current system was not structured enough in terms of the calendar 'to allow students to produce the best possible work for marks' (Department of Chemical Engineering: 2).

In proposing this change, the teaching staff was clear on several issues regarding the delivery of fourth year. They were clear that the fourth year needed to be offered as a package, thus limiting the number of third year courses that students were allowed to take alongside the full fourth year to one per semester. They were also clear that while this 'fourth year entry rule' had improved student performance, that design failures were still high. In particular with respect to the second semester design project, students fell short in two areas: the mass and energy balance section and the individual equipment design section. Finally, attempts to link cognate topics to other regular content in the business course by 'linking constraints and choices in a detailed design to economic performance of a design' (Department of Chemical Engineering: 3) did not improve the perceived lack of interest in the cognate topics in the business course.

These observations led to the proposal that the process synthesis course be extended to what is now the Process Synthesis and Equipment Design course to improve the 'backward and forward linkages' between business, equipment design and synthesis. (This meant adding the equipment design aspects to the process synthesis course and removing optimisation from process synthesis and adding it instead to the business course which previously handled equipment design topics). The new Process Synthesis and Equipment Design course would then be the major event in the first semester in terms of preparing students for the second semester design project. The staff further proposed that this course be taught through projects and exercises, and be assessed with

the requirements of design (second semester design project) in mind. This course then was the focus of the study in the second interaction phase.

All changes in the process synthesis course since the inclusion of the equipment design topics have been geared towards improving the learning experience of the students during the final design project in the second semester. Mr McAvoy, the convener of Process Synthesis and Equipment Design elaborates on this change.

> *From last year, we have been aligning the projects of the Process Synthesis and Equipment Design course to reflect the design project in the Chemical Engineering Design course. This was at the request of Prof Reed who felt that the students did not gain the learning experience of the flowsheet due to the great pressure that they were under in the final design project.*
>
> *(Mr McAvoy, email communication)*

The change that Mr McAvoy describes meant that the students started with the context of the final design project already in the Process Synthesis and Equipment Design course in the first semester of fourth year. In this way, Prof Reed believed students would be able to appreciate flowsheet development in a less time-pressured design environment. Finally, over and above the rearranging of some of the course contents between the business and the process synthesis courses, all instrumentation related contents were dealt with in the control course. In proposing that students be assessed through projects as opposed to written examinations, it was acknowledged that while this was ideal for student learning, designing a structured timetable to support this change would be crucial. It was further acknowledged that the reliance on groupwork as a form of assessment was problematic.

The above events meant that when the students started fourth year in Year 2, they entered an integrated fourth year system. This meant that the core courses over the first semester were arranged on a block basis ranging from two week blocks for some, to six week blocks for others. The intention here was to ensure that the students received contents at particular times during the semester and particularly that the design education they received was not only from Process Synthesis and Equipment Design but that these other core courses were able to contribute at appropriate times during the

semester. To this end, the students were presented with a block schedule which indicated when certain courses would be run and for how long. This is presented in Appendix C.

This model provided an example of a curriculum which, while not completely based on an integrated code, made attempts towards weakening the classification and framing values. Bernstein defined an integrated curriculum as one in which the various contents are subordinate to some idea which reduces their isolation from each other. He further suggests that this type of curriculum results in a common pedagogy and a common system of evaluation. Apart from the overarching idea which serves to weaken the classification among subjects, Bernstein argues that there has to be a weak classification of the agents involved, i.e. teachers or lecturers. In other words, they have to be in some sort of relationship in order to agree about issues such as assessment, pedagogy and the integrating idea, which in this case is design. This weak classification of lecturers is exemplified in this study by terminology in the proposal such as 'the 4th year lecturer's forum' and the fact that the proposal came from the programme committee and a number of the teaching staff in the department.

4.5.3 The Changes in Second Semester Fourth Year

In the second half of Year 2, convenership of the Capstone Design Project was taken over by Prof Reed. This change was first implemented in Year 2. Prof Reed took over from Prof Alcock who had been the convener for about ten years prior to Year 2. During Prof Alcock's time the students were given the project at the start of the second semester and apart from the individual oral examinations that some of the students were subjected to, there was very limited contact time between the assessors and the students for the duration of the design project. This created an environment where the design project was largely an assessment event with no structured time for teaching. When Prof Reed took over the course his intention was to change this with the aim of addressing several problem areas that he had identified regarding students' engagement with the design project. The first had to do with students' awareness of the importance of constructing a valid argument in the context of a design.

> *Students seem to be unaware of the importance of bringing their argumentation across, but failing to do so may result in failure in the course. Hence, feedback on their argumentation (more than on their calculations) is crucial in order to deliver a good design report.*
>
> *(Prof Reed, Email communication)*

According to this extract Prof Reed's concern was to put in place a structure that would allow students the opportunity to receive feedback in the context of the design, i.e. to make the evaluative rules explicit as opposed to just testing whether the students had acquired the realisation rules. In this way he saw himself as changing design from an assessment event to a learning event.

> *Design as a teaching tool rather than an examination tool. In my opinion, the 4th year students do not need an eight week assessment. The time should be devoted as much to learning as to a final assessment on the suitability of the candidate.* *(Prof Reed, Email communication)*

He further brings attention to two other issues, one of which was highlighted in Chapter 1 of this study. The first has to do with the second semester design invariably fulfilling a gatekeeping function so that weaknesses in students which should arguably be noted and addressed prior to fourth year reveal themselves at this level at which point it is too late for mediatory measures to be taken.

> *I often had the impression in the past that a candidate failing design could do better by repeating 2nd year courses rather than repeating design (, i.e. the failing came too late).*
>
> *(Prof Reed, Email communication)*

In second year students take courses such as mass and energy balances and other basic engineering sciences. This comment is congruent with the general view among staff that students perform poorly in mass and energy balances in the final year design but does not necessarily shed light on issues that have to do with report writing and argumentation in design.

The second problem area that he identified had to do with the attention the students paid to different aspects of the report.

> *The analyses of the problem associated with the design as depicted by the students in their report was typically at a low level, i.e. they typically performed the calculations at a high level, but the*

> *interpretation of the obtained results was poor…I have noticed over the last few years that a few hints can put the students on the right track and start analyzing in particular the economical, environmental and societal impact of design with respect to the engineering design implications, e.g. what are the high cost units (both from a capital and a operating cost view point) and what can be done about it in the engineering design.*
>
> *(Prof Reed, Email communication)*

According to him students tended to focus more on the calculations and not enough on the interpretation of the results obtained. He contends therefore that if students are pointed in the right direction through feedback in the context of the design project they could be alerted to these weaknesses and start to pay more attention to them. He is once again arguing for the opportunity to make design criteria explicit even in the highly pressured environment of the design project. This had never been done before in any structured or deliberate way.

The third and final concern had to do with the possibility of students copying.

> *Furthermore, the academic staff became nervous about possible copying amongst the students in the design studio. Hence, a final individual assessment was requested, which was built into the design program.* *(Prof Reed, Email communication)*

Prior to Year 2 individual oral assessments were conducted only for two groups of students: those who were on the first/second class border and those who were on the pass/fail border. However, the concern about the possibility of some students copying and therefore potentially not being entirely in control of their learning in the high stakes environment of design resulted in the introduction of the oral examination for every student. These changes therefore transformed the fourth year design project from being exclusively about assessment to the new model which included a formative component.

These changes meant that unlike in previous years the three major design reports - the mass and energy balances, the unit design and the economic analysis - would be submitted twice each. The first submission would be a preliminary submission on which the students would receive feedback before submitting the 'improved' final version. Secondly they were told that they would all be expected to orally defend their designs.

Prof Reed presented these changes in the form of a lecture to the fourth year class. Given that the fourth year was being run as an integrated unit where the material covered in the first semester was preparation for the design project, he decided to give the lecture at the start of the year during the first Process Synthesis and Equipment Design lecture.

In addition to informing the students about the changes to the design, he explained the objective of the Chemical Engineering Design course, which was to 'give students an opportunity to apply their knowledge of the fundamentals of chemical engineering to design a chemical plant' (2009a). He also told them that the emphasis will be on integrated thinking and defence of choices made in the design process (2009a).

The students were informed that the two courses - Process Synthesis and Equipment Design and Business Society and Environment - would tie in with design. These two courses were part of the integrated group of first semester fourth year courses as was presented in the previous section. According to Prof Reed, these two courses would provide additional tools in terms of the economic analysis, the environmental analysis, the impact on society and the hazard operability study. He told them that the projects in Process Synthesis and Equipment Design would be related to the Capstone Design Project and that the students would need to incorporate the results of the projects in Process Synthesis and Equipment Design to the design in the second semester. Parts of this talk were about Prof Reed letting the students know *what* the criteria for evaluation were. The detail of *how* the evaluative criteria were made explicit is provided in the Chapter 7.

The students were presented with a design book which included all the details of this introductory lecture as well as other details pertaining to the design project including course outcomes. He prepared a schedule which he presented to them during the lecture and included in the design book. The schedule is presented in the Appendix D.

This plan tabulates all the detail that had been verbally communicated to the students. Further it shows the strong pacing in the design project. The students were expected to start working on the individual sections of the project on the 15th of June which fell on the

start of the winter break. The submission for this was on the first day back from the vacation, Monday the 20th of July. This then was the first of the preliminary submissions. The students were allocated to groups but were expected to complete the mass and energy balance exercises and the designs of certain units individually. In providing the feedback, Prof Reed saw groups of students at a time but addressed individual students within the group. The same was true of the other feedback sessions. These were observed as part of the data collected. Towards the end of the project students were interviewed individually on their designs. Twelve staff members were involved in these interviews in order to manage the numbers involved.

4.6 Conclusion

This chapter has presented the cultural and structural conditions that prevailed prior to the introduction of the newly conceptualized design education. Ideas and beliefs that define not only the department, the faculty and the institution, but the Higher Education system as a whole have been discussed and presented, as well as some of the structures put in place in order to realise some of the ideals. No exhaustive discussion of the relations among these cultural and structural elements has been taken up at this stage. Rather, the data chapters that follow will present the interactions at the socio-cultural level, where the nature of the situational logic that agents have to deal with becomes more apparent. What will be of interest is the lived experience of the agents as they juggle their own concerns with those of the department and the institution. Issues of academic freedom and personal emergent properties will be taken up at that stage. The relations among the elements, whether of contradiction or of complementarity, will be entered into in the concluding chapter once the data has been presented.

Chapter 5
The Third Year Design Project

This purpose of this chapter and the two that follow is to present the findings of the research. As was detailed in the previous chapter the study is longitudinal; a group of students was followed over three consecutive time periods. These periods were second semester of their third year (termed Year 1), first semester of their fourth year (Year 2.1, i.e. March to June), and second semester of fourth year (Year 2.2, i.e. July to September). The three periods represent the interaction phase of a morphogenetic sequence T1 to T4. For ease of reference the data presentation section has been divided into three chapters with each chapter devoted to an interaction phase of the morphogenetic cycle. Of interest in these chapters is how students were able to exercise their agentic properties and powers in mediating the prevailing pedagogic structures towards realising their stated concerns. This chapter is organised into two main sections: the presentation of student – lecturer relations, i.e. the pedagogic practices, followed by student responses to these.

5.1 Pedagogic Practices – Student-Lecturer Relations

What follows is a description of how Prof Strauss' 'plan' was delivered during this first interaction phase in order to actualise his ideals about what is a legitimate design text. The ultimate aim of this practice therefore was to make sure that the students could produce legitimate text in terms of design at the end of third year.

5.1.1 Sequencing and Pacing in the Design Project

Pacing refers to the rate of expected acquisition, sequencing to the order in which contents are arranged and selection to which contents will be transmitted. Unlike in Reactor Design II (RDII) and Separation Processes, there were no formal lectures for the Third Year Design Project. There were forty-five minute sessions once a week designed to give some guidelines to students as they went along the process.

In an attempt to model the way of approaching any design project, Prof Strauss structured the third year design project in a specific way. He divided the project into five consecutive submissions in the order which, according to him, followed the logic of any design. In other words task 2 could not be completed without task 1, and task 3 could not be completed without task 2 and so on. He maintained there are key submissions which follow the logic of how any design is approached.

1. The physical data, the thermodynamics of the process, the reaction/s

   Anyway, we tried to get them going so I know they all have the data and next is the thermodynamics the reaction that they understand that, that's the first place to start

2. The mass (and energy balance)

   And then the next logical step as with any design is to look at the flowsheet ... and the whole idea is to do the mass balance. The energy balance is the added extra which I like them to look at, but it's not a criterion for make or break

3. The reactor

   next step that they do is the reactor …

4. The separator

   … and separator

5. The integrated whole

   Then that's the basic design elements of the two courses, now comes the higher thinking we want. (In) design they have to integrate all those (i.e.) the mass balance and those two units, looking at how this design works.

He also mentioned his justification for 'forcing' the students to submit these parts versus just giving them the project at the start and then expecting the finished product at the end. His intention was to make sure that the students all had each of the parts working and that they all had a chance to 'elbow this thing', as he put it. Further, he noted towards the end of the interview that this sequence gave the basic design elements of the two courses - Reactor Design II and Separation Processes – as well as detail about the design parts towards an integrated whole. The students here did not have control over the order in which they could approach the work. Prof Strauss had total control of the

sequencing of the contents. As such the framing over the sequencing is characterised as strong.

At the start of the project the students were presented with a project brief and an outline giving, among other things, information about the contact sessions and the order and dates of the submissions. The ordered submissions and their due dates are presented in Table 4.

Table 4: Third year design project submission dates

Due date (Year 1)	6 Aug	13 Aug	27 Aug	17 Sept	25 Sept	6 Oct
Submission	Physical and thermodynamic properties	Reaction thermodynamics	Mass and energy balance	Reactor design	Separator design	Final integrated report

This table represents the sequence in which the contents were arranged. Further, however, there was an expectation that by each of these dates, the students would have the realisation rules for each of the contents. What the above table implies is that the students needed to have part 1 returned if they were expected to use the feedback on part 1 for part 2 before the 13th of August as the students would need it to do part 2. Similarly, part 2 needed to be returned before the 27th of August as the students would have needed it for part 3 and so on. The period between the 25th of September and the 6th of October was eleven days. During that time they would need to get the separator feedback in order to put together the final design report.

This table illustrates that not only did Prof Strauss have full control of the sequencing but that he also had full control over the expected rate of acquisition, i.e. the pacing. Therefore the framing over the pacing is characterised as strong. The framing over the evaluative criteria in the design project will be discussed in a separate section.

5.1.2 Sequencing and Pacing in RDII and Separation Processes

In Reactor Design II and in Separation Processes the students were presented at the start of term with the course handouts which detailed the selection and the sequencing, i.e.

the different contents to be covered, and the order in which they were to be covered per week. The handouts also detailed the chapters from the prescribed textbook that would be followed and specific sections from each of those chapters. Therefore for both these courses the selection and sequencing is characterised as strong. Given that the handouts also placed expectations on students in terms of the rate at which they were expected to acquire the concepts (as evidenced by the contents to be covered per week), the pacing is also characterised as strong. Unlike the design project however, the two courses did not have specific submission dates for the contents. There were test dates, however, which are also evidence of strong framing over pacing.

5.1.3 Evaluation Criteria

Framing over evaluative criteria is about how lecturers specify requirements for the production of legitimate text. In the classroom context I was therefore looking for how the lecturers conveyed to the students what was expected of them as well as how they clarified concepts. In the students' text productions I was interested in how the lecturer made it known to the students what was missing in their text productions.

5.1.3.1 Evaluation criteria in RDII

The lecturer worked from handouts and the lectures were mostly about demonstrating how to arrive at certain equations which represented relations among key concepts in his course. Though he did not always use verbal cues, he always started by drawing a diagram and then establishing a starting point, using whatever information was provided in the problem context. At times questions were posed at students but usually he answered these himself as there was mostly no response from the students. This might have been because there was also not much eye contact between him and the students. He tended to focus his attention on his overhead transparencies. His main strategy was to illustrate the use of the diagram combined with the information about the problem context and other general assumptions not immediately obvious in the current problem (but relating to the general subject area under consideration), to narrow down the options for solving the problem. Each of these derivations took a couple of days to do so

that most lectures would begin with a statement such as 'where we left off yesterday'. In this approach therefore, there were attempts to make the criteria explicit.

Of course, within an evaluation context such as in tutorials and tests there are more opportunities for lecturers to make criteria explicit. Given that the aim of the Third Year Design Project was to foreground the design aspects of Reactor Design II and Separation Processes, the Reactor Design II lecturer was then also asked about how his course contributed to the idea of design. From this response the lecturer highlighted one way in which he made design criteria explicit in the lecture, i.e. by giving examples that he then followed with design-related considerations.

> *Then I do some basic examples and then I spend quite a bit of time talking about how they influence design decisions.* *(Dr Smith, Interview)*

In this response he mentions two such key design considerations: reactor size and the economics. Towards the end of the second week he started to talk to the students about the relationship among different variables which influence reactor size. In this detail therefore the lecturer believes that he is making design criteria, with respect to designing reactors, quite explicit.

5.1.3.2 Evaluation criteria in Separation Processes

In Separation Processes, the engagement was such that there were instances when the students pointed out to the lecturer his errors on the board, which could be potential areas for making evaluation criteria available. However this potential was often not realised due to the lecturer's response, which on several occasions amounted to, 'I will get back to you on this tomorrow', but in most cases he did not, even though in later discussions he apparently thought he did.

Additionally, part of the course was not taught by the main lecturer but by a post graduate student who had never lectured before and was asked by the main lecturer to 'step-in'. He took over the lecturing in the last two weeks of the third term. In terms of transmitting criteria in general, he tended not to ask questions of students. He tended

also not to talk much. On a typical occasion he wrote an equation on the board with no explanation of how he had derived it. After some murmuring from the students who were trying to follow, one student asked him, 'How did you get that?' In answering this question, he started writing on the board, talking to himself for about five minutes with the handwriting getting smaller and smaller as he was trying to derive the equation. After a while, seemingly with no success he said 'I will get back to you tomorrow'. He then asked: 'What else confuses you?' to which there was no response from the students. He carried on writing on the board and drawing some diagrams after which a student asked: 'What are you showing us?' His response was, 'How to draw the line, we will see if we get there'. In his lectures therefore he did not make evaluative criteria explicit in any systematic way nor were the opportunities created by students to clarify issues taken up by him in terms of making criteria explicit. On those occasions when he did answer a question, he walked up to that student who asked the question and talked to them directly, not addressing the entire class.

In terms of criteria that speak specifically to the design, such as the use of a computer package named ChemSep, the observation of practice revealed that this was taught in the last three lectures of the third term by the post graduate student and these lectures were not compulsory. Attendance dropped considerably as students had an assignment for another course at the end of that week. The lecturer used the computer to teach this part of the course. It was a demonstration-based course where he showed the students how to set up parameters and specify variables when separating components. He also showed them a phenomenon which the students knew in theory but had never witnessed before, i.e. that components with boiling points that are close are hard to separate. He also demonstrated incorrect feed positioning as well as how to fix it.

Finally he demonstrated several types of flash calculations. One student asked him what a reflux drum was and he said, 'It's a container where stuff comes from the condenser. It keeps a constant value of the liquid'. After this, he asked the students, 'Do you think you could use ChemSep now?' to which the students answered, 'Yes but not very well'. He

concluded by stating, 'ChemSep gives you a way of seeing what is happening inside the distillation column'. This being a visual lesson arguably the criteria were slightly easier to acquire.

The Separation Processes lecturer was asked about how he would like to see students apply his course to the design project.

> *In a way the tutorials in this course are, very quickly basically get into mini design exercises already so I would like to see a more natural succession from the kind of prototype problems to slightly bigger problems which can go into design.*
>
> *(Dr Johnson, Interview)*

In his response the implication is that although nothing is overtly done in lectures, the tutorial problems are such that students in a sense are already dealing with design situations in their tutorials, albeit at a smaller scale.

5.1.3.3 Evaluation criteria in the design project

In order to characterise the framing over the evaluative rules in the design project, Prof Strauss' practices with respect to feedback were the main focus area. This refers to feedback on students' scripts as well as any verbal communication on issues related to the design project. Earlier the framing over the pacing and selection were both described as strong. This means Prof Strauss put considerable emphasis on insisting that the students submit the contents in a specific order at a specific time as he argued that this was the best way in which students would learn the contribution each course made to design as well as how to create an integrated whole. Table 5 indicates the dates on which the submissions were due and the dates on which Prof Strauss returned the students' scripts.

Table 5: Dates on which marked student design texts were returned

Due date (Year 1)	6 Aug	13 Aug	27 Aug	17 Sept	25 Sept	1 Oct	3 Oct	6 Oct
Submission	Physical and thermodynamic properties	Reaction thermodynamics	Mass and energy balance	Reactor design	Separator design			Final integrated report
Return dates								
Submission						By this date only the first three had been return-ned	Reactor feedback	Separator feedback

As can be seen, just under a week before the final submission was due only the first three submissions had been returned. On the due date of the report, the second to last submission, i.e. the separator report, was returned. While the framing is strong in terms of pacing and sequencing, the lecturer, in giving feedback to the students was not able to keep to this framing in order to make the evaluative rules explicit to the students. It seems that the evaluation of the projects was a mammoth task, the magnitude of which Prof Strauss had not anticipated.

In the absence of feedback the students were not in a position to know whether their work was correct or not and would therefore have potentially carried mistakes over to subsequent submissions. In particular, they received the fourth submission (the reactor report) two days before the final submission was due which meant they had two days to fix whatever errors were highlighted by Prof Strauss in submission number four as well as try and design a well functioning distillation column (the fifth submission) in the absence of feedback, for the final report. This situation meant therefore that the lecturer was no longer making design criteria explicit through feedback on submissions. It was left to the

students to use other resources to do this. The control then had shifted from the lecturer to the students, making the framing over the evaluative criteria weak.

It was observed in the three contexts - Reactor Design II, Separation Processes and the Third Year Design Project - that white students tended to occupy the first couple of rows in the class. The white students often had conversations with the lecturers, often interrupting them during the lecture to engage with them over the work. This same freedom to communicate with the lecturer was not observed with the black students. This issue will be explored further in due course.

5.1.4 Classification - Separation Processes, RDII and the Third Year Design Project

Prof Strauss in his extract talked about how the integrated design project was meant to foreground the design aspects of Reactor Design II and Separation Processes. Thus, the relationship between the two courses and the design project needed to be investigated. To do this, the lecturers of the two courses were each interviewed about the design project and in particular about how and where each of their courses fitted in. The response of the Separation Processes lecturer indicated that he was neither involved in the design project nor did he have knowledge of where his course fitted in the course design.

In his response the Separation Processes lecturer states that he was not involved in the project and wasn't aware of some of the things that the students were expected to do. Prof Strauss' intention to make the relations between the two courses explicit through the design project was not realised because the other two lecturers were not involved. Instead, there was a tension between the two courses and the design project. This tension is best described by the use of the concept of classification. Prof Strauss intended to achieve a situation where the classification between the two courses was weakened in order to achieve their integration through the design project. However the lack of involvement in the design project by the lecturers of the two courses meant that the design project, Separation Processes and Reactor Design II were not related and that no

links were facilitated by any of the three lecturers involved. As such this situation served instead to preserve that insulation. The repercussions to the students of this condition are analysed in due course. The Separation Processes lecturer was further concerned that attention needed to be paid to pacing and sequencing.

> *I get the feeling that some people [the students] were asked to do things way before I covered them in my lectures and I wasn't at any stage informed that that was going to happen, … I might have rearranged my lecture material but I would even say that design should be shifted by four weeks not start until the last term… (Dr Johnson, Interview)*

The strong classification between the three courses further compromised the sequencing and pacing between them. The absence of the links meant that in each of their course designs, the Reactor Design II and Separation Processes lecturers were not necessarily mindful of what was being done in the design project. The Separation Processes lecturer quoted above implies that if he had been aware and involved in the project, he may have exerted some influence by either rearranging his lectures or suggesting that the design project start later than what it actually did. As things stood he was not in a position to make that decision. He thus had a different view on the rate at which he expected students to acquire design concepts, i.e. four weeks later than what Prof Strauss expected. Further, Prof Strauss was himself not aware of when certain concepts were being introduced in each of the two courses.

From sitting through lectures and observing the dates on which the Separation Processes material was introduced, it seems that the students had been given the distillation column design tool before they were expected to use it in the design project. Despite this, however, the Separation Processes lecturer's feeling was that even if the material had been properly sequenced between the Third Year Design Project and Separation Processes, the concepts were too new and would have been difficult to apply for at least some of the students.

In his interview Dr Smith did not refer explicitly to his involvement in the design project. However, this interaction with some of the students and my observation of what was

going on throughout these courses indicate that he was not involved. His comments on the third year design project were the following:

> *I think that the third year project does show a little bit of integration in that regard. The students did comment on it and I do think it reinforces what I teach in the course or it's the other way round. That's the one thing I see in third year project, there's quite a good interaction there…*
>
> *(Dr Smith, Interview)*

In this extract Dr Smith seems to think that there is complementary work going on between his course and the design project. However, student interview data indicates that, just as in the Separation Processes course, the Reactor Design II lecturer was not involved in the project himself and did not know much about it. The strong classification between Reactor Design II and the design project does not seem to have caused many problems. This is largely due to the fact that the knowledge the students would have needed to design the reactor was partly dealt with in a first semester reactors course, as well as quite early on in the second semester. For this reason, the students would have had the reactor design knowledge by the time they needed to use it in the design project.

Moreover, the design of the reactor model required use of material from other courses that would have been covered either in second year or in the first semester of third year. The argument being made is that the total design project experience would have been enhanced had the classification between Separation Processes, Reactor Design II and the design project been weakened.

In conclusion therefore, while within the design project itself Prof Strauss was in full control of the framing over the pacing, the selection and the sequencing, the strong classification among the three courses - Separation Processes, Reactor Design II and the Third Year Design Project - resulted in weak framing over pacing and sequencing across all three courses. This, as indicated, compromised the explication of evaluation criteria (which were described as weakly framed). Additionally, the strong classification allowed the lecturers of Reactor Design II and Separation Processes to keep their distance from the Third Year Design Project and to thus not exercise their agency in possibly making input to the structuring of the design project.

While the three courses are seemingly insulated from each other, students' performances in the design project had a direct effect on their performance in Reactor Design II and Separation Processes as indicated earlier. It seems therefore that there were explicit rules (at the level of structural conditioning) which defined the nature of the relations among Reactor Design II, Separation Processes and the design project as far as the marks distribution were concerned which allowed for a weak classification. However there was a more tacit set of rules (at the level of social interaction) which defined the relations among these three subjects which served to preserve the insulation so that these three subjects were not allowed to link to each other. Prof Strauss introduced the integrated design project in order to teach the design process. Part of this required that he provide feedback to the students to match his pacing demands. He was not able to achieve this and the next section looks at students' responses to this situation, in particular their efforts towards inferring realisation rules and what they did to get the rules despite the weakly framed evaluative rules.

5.2 The Relations – Students' Experiences

The previous chapter provided some detail about each student in the sample. The weak framing across the sequencing of the contents in Reactor Design II, Separation Processes and the design project created potential[23] constraints. They created a limited range of options from which each student's formulated plan of action could be understood. These action plans formulated by the students were against the backdrop of their formulated concerns and projects. To understand the students' experience during the interaction phase, they were interviewed and allowed to discuss the range and outcomes of interactions that took place over this period. Whilst the realist approach seeks causal explanations where mechanisms at a deeper level of reality are used to explain surface phenomena, this does not come at the expense of the meaning that individuals attach to those phenomena. The stratified view of reality contends that seeking causal explanations

23 Potential as this would of course depend on the students' defined projects.

and understanding the meaning that people attach to their situations are not in conflict with each other.

In brief, the students were asked to define their concerns and projects as well as to define constraining and enabling situations they had encountered to date. These responses are presented first. They were also asked to talk about their design experiences generally, and their responses to the feedback practices. These responses were categorised according to the resources the students used in the face of the available pedagogy. The concepts of student/student relations, situational imports and reflexivity were used in the analysis.

5.2.1 Concerns

The students' concerns were categorised according to whether they were natural, social or practical in nature (Archer, 2000). The practical concerns were classified as those reflecting an emotional response induced by the student's relation to their work (the work being the object). The object constitutes a series of tasks at different times which all make demands on the students. What is reported are students' accounts of what constantly occupied their minds and what they 'worried' about the most. It needs to be noted that what is reported is what is stated by the student. Therefore no inference is made about something not stated being non-existent. This distinction becomes important in later chapters as more data is revealed. The students in the study fall within a narrow age range, all pursuing a chemical engineering degree. In light of this it is therefore not surprising that most stated concerns were in the practical order and more specifically with performative competence in their studies generally.

Practical order

The students named specific areas of concern related to achieving performative competence in the practical order, the things that were the subject of their *Internal Conversation*s. In particular they worried about the rate of expected acquisition and thus

defined themselves as poor at time management or lazy or failing to understand concepts.

The rate at which they were expected to acquire concepts created situational imports for some of these students. One emotion related to this situation is frustration, implicit in the response below.

> *Third year, this year, is very difficult for me ... but for now work is too much for me, I can't handle it ... I think I'm having problems with Separation Processes…I'm not sure if the reason I'm not understanding is I'm not enjoying it. I'm just not getting the thing…* (Nolwazi, Interview)[24]

The difficulty she is experiencing in Separation Processes threatens her performative competence hence the desperation seen in statements such as 'it's very difficult for me', 'it's too much for me', 'I can't handle it'. The next one is not as emotionally charged but is nonetheless telling regarding the stress created by living up to the rate of expected acquisition which gets worse in the latter part of the programme.

> *In first and second year you could finish a tutorial in one afternoon and then it was done. Now you work the whole tutorial session and the whole afternoon and the whole night and you're still panicking to get it finished…* *(Mike, interview)*

This sentence does express some concern that due to the magnitude of the work, he spends many hours at it, i.e. the task, but doesn't achieve the sense that 'it is ready to be handed in', 'you're still panicking to get it finished'. One student commented that he was worried that they were not given adequate tools to do what they were being asked to do. His perception that he is not being adequately prepared to do the work worries him in that he feels he may not then be able to achieve performative competence, understand concepts or manage the workload.

Social order

Some students expressed concerns in the social order such as losing friends. In the social realm Archer argues that our most important concern is self-worth which is vested in certain social projects such as career, family, church etc., 'whose success or failure we

24 Interview transcripts have been edited. Thus ellipsis marks indicate telling repetitions or hesitations that have had to be sacrificed for readability, while attempting to retain some sense of expression in the spoken interview. Frequent repetitions of filler words such as 'like' and 'you know' have been deleted with no loss to the meaning.

take as vindicating our worth or damaging it. It is because we have invested ourselves in these social projects that we are susceptible to emotionality in relation to society's normative evaluation of our performance in these roles' (2000:16). Some of this is seen in one student's response.

> *I've lost my social ability. I can't talk with much people … I don't have time to sit down and ask, 'Hi, how are you, how are things?' So I avoid people ... I feel like all my time has been dedicated to work… (Kathleen, Interview)*

The student grapples with the issue of how much of her time she can realistically afford to have vested in her friends given the demands of work. There is here again an implicit frustration that she is no longer able to socialise. She uses the words 'loss of social ability' which imply that at some point in the past she was vested in this social project with some success but that position is now no longer tenable.

Natural order

Some students expressed concerns in the natural order such as getting sick. In the physical realm, therefore, it seems the students' physical well-being is compromised by the stress that the work has put them under. The volume of work is depriving some of sleep and others of physical activities such as sports. For others the consequences are compromising their physical health.

> *That's what worries me a lot lately ... there's just so much to do ... you cannot afford to sleep ... I ended up not sleeping because I couldn't afford ... to sleep ... obviously after an hour my body died … but my mind was like, 'There's no peace, the work is too much'… (Gontso, Interview)*

This extract gives a sense of someone grappling with the question of whether to sleep or not. There's desperation here again: 'the work is too much', 'there's no peace'.

What is clear from this evidence is that the concerns the students have in the practical realm are the basis for the concerns in the social and the natural realms. Their project of achieving performative competence seems to come at a price. The other two realms are being compromised which in some cases further compromises the performative competence project, as in a vicious cycle. One student notes that

> *I'm concerned about, I don't have that much time anymore to exercise, stuff like that. I can feel affecting the way I do my work as well… (Devon, Interview)*

Due to the demands the work places on him, he has no time to exercise but he can feel this affecting his work negatively.

According to Archer, a dilemma confronts all people in that every person receives all three kinds of emotional commentaries originating from all three orders of reality. This requires that they attend to all three clusters simultaneously. The emotions may not dovetail, however, and 'it follows that the concerns to which they attend cannot all be promoted without conflict arising between them' (2002: 16). These student quotes illustrate that the concerns are in conflict and that the students have to subordinate other concerns in order to prioritise performative competence. The extracts also seem to indicate that for these students the practical realm has primacy since it seems to be the primary source of the emotionality they exhibit in the other two realms.

5.2.2 Constraining and Enabling Situations

While the structures have been defined as potentially constraining due to the weak framing across the sequencing in the contents of the design project, Reactor Design II and Separation Processes, it was necessary to establish whether the students did in fact see them as such and what other situations they found constraining and/or enabling. The students were asked to talk about what they thought made their academic life difficult or what hindered their academic achievements. These responses were clustered under four categories: the chemical engineering programme, interpersonal relations, family and living situations and personal traits.

The issues pertaining to the chemical engineering programme included statements made to students by academics as well as provisions of the programme that students perceived to be inadequate for them to achieve performative competence. The first two quotes are statements made by academics to students which served to demoralise them and affect their self-confidence.

Just gaining confidence in yourself … I'm from a government school and you know when you get here and they tell you that the education that you got was not enough. Like, we

hear that everyday and it kind of dampens your mood as such.

(Katleho, Interview)

There are certain things that some lecturers said to me that I found quite discouraging and stuff ... he told me I must have a crack in my head if I thought I would be able to manage…

(Petrus, Interview)

The issues related to perceived poor programme provision had to do with the quality of the tutoring, poor offerings with respect to computing and unhelpful lecturers.

There are tutors that will ... take you further into the darkness. There are certain tutors that do not prepare… *(Petrus, Interview)*

At the moment I'm finding one aspect of my engineering knowledge that's holding me back and I think most people are finding that, a lack of computer efficiency, for want of a better word.

(Devon, Interview)

In the second category were issues related to interpersonal or interracial relations and included statements about what students identified to be important in getting through the degree, i.e. relating to student relations in the same class.

Groupwork … sometimes it's really hard to work with white people; even though you're willing, I don't know how much they're willing. They sort of still have that (idea that) if you're black your capacity is limited in a way and you must take the back seat of things and just look in to what's happening and what they're doing. And so I find that to be quite stressful.

(Petrus, Interview)

Like in first year or second year I was not used to working with most people. I would only go to people that I know, and with people that I didn't know I wouldn't even go and ask questions. So I guess that was another problem because with chemeng you need to know everyone.

(Nolwazi, Interview)

It seems that for Petrus the area that causes the most stress for him is being perceived as 'limited' due to the colour of his skin. This appears to have been further exacerbated by the practice of groupwork favoured in some aspects of the degree programme. Nolwazi talks about the limitations of not knowing everyone in the class, alluding to the fact that you need to know 'everyone' in order to get on.

In the third category are family and living situations. The issues here were distance from campus in terms of accessing resources as well as lack of sympathy from friends and family members who did not understand the difficulties related to studying chemical

engineering. Some students felt they bore quite a burden as the 'saviours' of their families. These two quotes refer to that.

> *The home pressure; everyone is looking at you. You're the only one in the family who's at varsity and everyone is waiting for you to graduate; there's a lot of pressure as well.*
> *(Katleho, Interview)*

> *I come from a very very poor family. I grew up thinking I am the only one who is supposed to help these people, I am their only saviour.* *(Thabang, Interview)*

Thabang and Katleho again are some of those who have extricated themselves from their social origins in order to pursue their project. They express the stress associated with this decision which they live with almost all the time. The final category consists of personal traits that students felt let them down. These were generally laziness and procrastination.

This data indicate that these students operate in an environment which is cognitively demanding and which presents constant challenges to them. Certain aspects of the programme threaten their concerns of achieving performative competence and as such are constraints. However, for black students, there appear to be further constraints created, on the one hand, by lecturers who frequently remind them of their inferior educational origins and, on the other, by other students who (according to Petrus) view them as inferior academically. It seems that, over and above dealing with programme challenges, this group of students as part of their daily experience also has to deal with people's notions of what they can or cannot do due to their social origins.

Such notions create a constraining contradiction in that the cultural system in chemical engineering is dominated by beliefs that students in the degree are academically strong and capable. But in the course of socio-cultural interaction this is qualified by statements that actually some students, given their background, may not be as strong academically and may not succeed. That message, while not always verbal, may be pervasive. These issues illustrate again that the students' Internal Conversations revolved around those issues that had the most impact on their ultimate concern which was to achieve performative competence.

5.3 Framing of Evaluative Criteria – The Internal Deliberations

The previous section was necessary to give an indication of what these students deliberated about the most. The following section's focus turns to students' responses to the feedback practices in the design project. Specifically, what is of interest is how the students deliberated over the constraining situation created by the weak framing over evaluative rules in the design project. On the basis of how they carved a way forward towards inferring realisation rules, and in their general deliberations about the issues surrounding the design project, they were characterised as autonomous, communicative or fractured reflexives. Archer (2003) notes that even in work situations where tasks are to be completed, autonomous reflexives become communicative reflexives for the purposes of having issues clarified to them. This is not necessarily predictive but is rather indicative perhaps of the gravity of the situation in which the students found themselves. Quite a number of the students took pride in the academic independence they enjoyed as autonomous reflexives: to not have to ask for academic help and have the ability to complete work on their own was quite important for some of them as will be seen.

5.3.1 On the Late Feedback – Students' Use of Resources

Some students demonstrated autonomous reflexivity in independently being able to identify their own errors and in then independently being able to fix those errors even without the feedback. The students received feedback for the final task at 10:00am in the morning and the final report was due at 4:00pm of the same day.

> *I had to completely change my approach so I changed from excel to code. With the separator model it was very different though because we got that back on the day. So all the things he had spoken about in my first separation model [the one which was returned on the day] which I knew weren't right… (I) just did it my own way and everything he pointed out to me I had redone correctly. So for me it wasn't such a big thing.* *(Tanya, Interview)*

Tanya seems to have been aware of the issues with her work as she was submitting it. She then fixed all these things for the subsequent submissions so that the late feedback did not affect her.

Nazlee reported that the weekend was the only time that she and a group of her friends she was working with had to try and fix their errors. She speaks about handing in her final report and then on the same day getting her separations submission back.

> *What's worrying me is that I handed in my final design… and then I saw the distillation…I didn't have it at all… And we actually had to correct things from there: conversion and stuff, and we had to change everything. You had to change your code basically and we only had the weekend. We went to him (and asked): 'Please can you give us an extension'. There were eight to ten of us that went and he said, 'No I'll give you until five o'clock'.* *(Nazlee, Interview)*

Nazlee does not speak of having been aware of issues beforehand but she speaks of changes that she and a group she was working with had to make. Unlike Tanya, Nazlee's first port of call was to appeal for an extension with a group of her peers. When this was denied they sat down together to work things through. She demonstrates communicative reflexivity in appealing to the group for collaboration and in exercising collective agency with her peers in attempting to have the date moved.

This next student had a different approach to addressing his errors.

> *Our errors, we would try to correct them afterwards but that was asking people who got higher marks…* *(Tariq, Interview)*

Tariq responds differently to Tanya and Nazlee. While Nazlee appeals to a peer affinity group where they worked together to resolve errors, Tariq's approach was to ask 'students who got higher marks'. There is a sense of the communicative in Tariq but his singling out a student with higher marks meant he went beyond an equal to appeal rather to an expert.

The extracts were examples of the three general strategies in terms of the late feedback, i.e. students who by and large 'sorted' themselves out, students who appealed to peer groups and then attempted to exercise collective agency and those who went to 'student experts'.

Some students noted that they wanted to be able to have an idea of Prof Strauss' thinking and were hoping the feedback would provide that. They expressed frustration at not knowing what was expected of them and then at not receiving feedback to guide them.

The general approach towards fixing errors was geared towards changing the computing language.

Prof Strauss commented earlier about the importance of the big picture in design, where you put all the parts together and then you go for the extra step of integrating and making it all come together. The student comment expresses how the lack of feedback impacted on that.

> *Well it would be nice if we could get our Separation Processes and our Reactor Design II back because we've got to optimize this before Monday. How do I know if I was on the right track? If I've messed my Separation Processes thing and I don't realize it then how am I going to optimize it…even if he hasn't give it back to us we will still talk about it. It should be fine.*
>
> *(Taryn, Interview)*

Taryn is confident however that it will work out in the end because she will talk about it with her friends in class. She also represents another who was concerned about not achieving performative competence and then appealing to friends to complete the task.

From these interviews it is becoming clear that students started to work as collectives and used each other as resources in the absence of feedback. There were variations to this though from students who still appeared to maintain a level of autonomy even though they still consulted with friends, such as Devon, to those who seemed to have had friends as their starting point, such as Nazlee and Tariq. Nazlee and Tariq and some of the other students also tended to speak in the plural so that it was never 'I' who did the work but rather 'we'. Their deliberations therefore started to point to communicative reflexivity.

Tanya is the only one who in her individual capacity approached the lecturer to bring about a change to her own personal circumstances. None of the other students did this. She therefore starts to exhibit autonomous tendencies. It is noteworthy that she was no less emotional than Thabang, for example, but she seemed to achieve more of a favourable outcome for herself than did Thabang or any of the others. Considering that the students found it important to have good networks in the class, it is quite clear, particularly in the absence of feedback, that not having these could have been detrimental to some of the students. Table 6 shows the manner in which all the students in the sample used resources for this interaction phase. A distinction has been made

between their preferred strategy versus the strategy they used in this particular context. This distinction gives further information about whether after assessing their options the students altered their preferred ways of working.

Table 6: Students' use of resources

Student	Population group	Preferred approach towards the use of resources	Approach adopted in this context[25]
Brian	White	Works with friends	Worked with friends
Devon	White	Prefers to work alone	Had to consult friends
Gontso	Black	Prefers to work with friends	Worked with friends
Kathleen	Chinese	Prefers to work alone	Worked alone
Katleho	Black	Starts off on his own in general	Had to consult friends
Kelly	White	Works with Mike	Worked with Mike
Mike	White	Prefers to work alone	Worked alone
Nandi	Black	Prefers to work alone	Worked alone
Nazlee	Coloured	Works with friends	Worked with friends
Nolwazi	Black	Prefers to work with friends	Worked with friends
Petrus	Black	Works alone	Consulted with friends
Tanya	Coloured	Works alone	Worked alone and pushed for her marks to change
Tariq	Indian	Prefers to work with others (not necessarily friends)	Worked with others
Taryn	White	Prefers to work alone	Consulted with friends
Tasneem	Coloured	Prefers to work with friends	Worked with friends
Thabang	Black	Prefers to work alone	Worked alone
Zunaid	Indian	Prefers to work alone	Consulted with friends

5.3.2 Inconsistencies in the Evaluation

Over and above the lack of feedback, as outlined above, the students deliberated over the meaning of the feedback when it was available. Meaningful feedback, where the lecturer lets the student know what is missing in their text, is crucial in terms of their ultimate concern of achieving performative competence. This long quote gives an idea of this.

> *I found the feedback terrible. There was no consistency in my opinion between what you did, what he told and your mark. For example my highest mark was for my reactor model where I didn't even*

25 The use of the word 'consulted' means the students used friends for verification purposes versus those who used friends as a starting point. These are usually the students who acknowledged the need to attempt to achieve performative competence on their own.

> *have a temperature drop but had a temperature increase and I had that as my highest mark. The things he wrote in no way helped me and the only way I got any feedback was to fight it out with and going to see him and saying, 'What does this mean?' And I mean the reason I resubmitted my mass and energy balance (was because) I didn't like my mark. I went to him and he said 'Oh when I marked that I was tired. I just gave you the mark'. Now things like that are really frustrating because you're working at it for like eight hours and he says: 'Oh I was tired and I gave you a mark'. And he says to me 'Well it looks too good so I couldn't give you ten' and that frustrated me, and that put me in a certain frame of mind for the rest of my design project. I was sending emails and begging for meetings and lurking in the corridors so I could jump on him.*
>
> *(Tanya, Interview)*

Tanya points to several issues here. She was not able to link her grade to her performance at any time. Her attempts to rectify the situation amounted to going to see the lecturer for an explanation and/or a remark. These exchanges with the lecturer seem to also have been sources of frustration and anger at the lecturer's perceived *laissez-faire* approach to the assessment. She seems to have persisted however despite this. Her autonomous reflexive tendency noted previously is reinforced by this situation.

The following student, who has achieved top of the class across the years, commented that he didn't understand why he had got a ten (out of ten) for some of the submissions.

> *I don't know how I got ten because I didn't put R_{min} or any of that so…I'm not quite sure how it works because I didn't put a whole lot of things in so…* *(Mike, Interview)*

R_{min} is one of the fundamental concepts in designing a distillation column. According to this student the inclusion of R_{min} in the report is non-negotiable. In putting together the report it seems he had left out quite a few other things that in his opinion were quite crucial. As a top student he felt confident that he knew what was important enough to be included in the report. His getting a ten therefore, having left out some of this important information, puzzled him.

Another student takes issue with two things; firstly being given a ten (out of ten) and then still being told that her work had errors. According to her a ten means everything has been done perfectly. The second issue is that of how much of her work Prof Strauss actually read.

> *He didn't actually read my stuff. But he still gave me ten. So I don't understand why he still gave me ten if I did it wrong…So I don't understand; I'm going to ask him why. You know if you give me ten then you should, there shouldn't be anything wrong…* *(Kathleen, Interview)*

Kathleen demonstrates her autonomy here in stating her intentions to ask the lecturer about his marking. It seems from the three extracts that Prof Strauss was not able to give meaningful information to the students about their text productions.

Thabang is another autonomous reflexive who expressed frustration at what he considered to be the lecturer's preference or his failure to read his work deeply enough.

> *What I hate most, he never reads our theory, never ever. He never reads. And then for me what I didn't like about how this project is, they chose something, someone who does modeling, the person who likes modelling. I don't think the person likes theory at all. I don't think so at all 'cause what he does when you submit something is go straight to the results and…doesn't look at the thinking…he doesn't…If it's not what he was expecting you get it wrong and you never understand how he marks. This is so frustrating!* *(Thabang, Interview)*

It frustrated Thabang that Prof Strauss, who is known in the department as a modeling expert, did not appreciate his efforts at expounding on the theory. He felt that his thinking was not appreciated or valued and that instead all Prof Strauss cared about was the result.

Other student comments were associated with what they perceived as inconsistencies in the lecturer's verbal feedback during the contact sessions.

> *All along there were two main problems. One was Prof Strauss said something one week and the next week he'd said that was wrong.* *(Brian, Interview)*

Brian points to two issues. The messages they were given during the contact sessions differed from week to week. It also seemed that Prof Strauss had mentioned to the students that the contact sessions were a privilege and not a right. Given his espoused commitment earlier about guiding the students through each stage of the project it is puzzling that he might not see the sessions as crucial in explicating design criteria and assisting students to produce legitimate text. It seems that this student like most of the others takes comfort in working with his classmates in trying to consolidate the seemingly contradictory ideas.

5.3.3 The Use of Other Courses in the Design Project

In the context of the strong classification between the Third Year Design Project, Reactor Design II and Separation Processes, the manner in which students were able to use the

three courses was of interest. The point was to have a sense of how the students dealt with the strong classification between the three courses.

In designing the reactor the students seem to have used tutorials from the Reactor Design II course thus treating the reactor design aspect of the design project as a Reactor Design II tutorial. In many cases this amounted to using the exact format of the tutorials and changing numbers around. For Separation Processes, they made use of the tool ChemSep. For most of the students this amounted to 'playing around with numbers until something worked'. Most did not appear to understand the significance of the results or of what they 'fed' the programme.

What has emerged thus far is that the strong classification between Reactor Design II, Separation Processes and the design project resulted in weak sequencing of contents across these three courses. This meant that the strong framing over pacing demanded in the design project was at odds with the sequencing of the contents between the three courses thus further compromising the explication of evaluative criteria in the design project.

5.4 Conclusion

In accordance with the morphogenetic approach, this chapter presented the first interaction phase which took place from July Year 1 to October Year 1. The interaction phase was an account of how Prof Strauss, the new lecturer of the design project, worked with the new structure towards helping students realise legitimate design text. His main strategy was to explicate evaluative criteria in design by setting up a strongly framed practice in terms of pacing and sequencing. This meant he was very careful to make sure students submitted certain contents in a specific order which he felt best demonstrated the logic of any design. However, he was working within a curriculum system with strongly classified subjects and discourses. The aim of the design project was to weaken the classification between two of these discourses in particular, namely Reactor Design II and Separation Processes.

However, in his practice Prof Strauss preserved the insulation by not consulting with the lecturers of these two courses. This meant the classification among the three subjects was strong and the sequencing of contents specific to the design (in Reactor Design II and Separation Processes) was weak. This weakened the framing over evaluative criteria in the Third Year Design Project resulting in what Bernstein terms an invisible pedagogy.

Furthermore, the pressure felt by the students to live up to the strong framing over pacing in the design project did not go unnoticed by the lecturers of the other two courses. They commented on how they wished they had known about the events in the design as they felt they might have then rearranged material in their courses. Ultimately, however, they were happy to preserve the status quo as they were busy with many other commitments and activities.

The interaction phase was also an account of the consequences of the weakly framed evaluative criteria, a structural emergent property, to the students' stated concern of achieving performative competence in design. It gave an indication of how the students mediated this structural property towards inferring realisation rules. The invisible pedagogy threatened the students' concerns of achieving performative competence. This created situational imports for the students caused by the late feedback and the inconsistent messages from the feedback when it was available. In assessing their range of options, which were invariably narrowed (given that they could not, for example, use the lecturers of Reactor Design II and Separation Processes as resources), the students tended to do one of three things. In realising that they were running out of time, some students exercised some autonomy and chose to fix errors for themselves or approached the lecturer individually with queries with successful outcomes for some (for example Tanya). Others decided to work together, developing common strategies (such as Nazlee). Some exercised collective agency and tried to have the submission date changed with no success. Lastly there were a small number who decided that even though working with a group was beneficial, it would be even more beneficial to approach people who were known in the class to be academically strong (such as Tariq).

It seems that while pedagogically the classification was strong between Reactor Design II, Separation Processes and the Third Year Design Project, programme structures for the calculation of year marks allowed for there to be a link between the three courses in terms of the marks structure. This meant the marks obtained in the Third Year Design Project contributed to the final marks of Reactor Design II and Separation Processes, since the project was not a stand-alone course. Three of the students did not achieve the pass mark of 40% which was necessary for them to gain entry into the examinations for Reactor Design II and Separation Processes. The issue therefore of whether the students had the realisation rules for design at the basic level was under question at the end of Year 1 as, despite failing the project, they progressed to Year 2 in fourth year. The final grades for the project for each student are included in Appendix G. Due to the appeals process in the faculty, the students were allowed entry into the examinations.

The interaction phase continued into the following year when the students were in fourth year. The detail of this continuing design education is presented in the next chapter.

Chapter 6
Process Synthesis and Equipment Design

The purpose of this chapter is to present the findings of the next phase of the longitudinal study which is the first semester of fourth year in Year 2 which ran from February to June. The chapter is organised into two sections, the pedagogic practices and students' responses to these. Finally, in the concluding section, the key findings from the previous chapter which detailed the first interaction phase are referred to briefly in the context of the findings of this chapter.

6.1 Pedagogic Practices – Student-Lecturer Relations

The course of interest here is Process Synthesis and Equipment Design. Mr McAvoy lectured in this course with another colleague, Mr Denver, who was responsible only for the computer modeling aspect. The modeling lectures started during the third week of the term and were held in the design computer studio. For these lectures the students were given several manuals and the sessions were run as a tutorial in the presence of the lecturer and several postgraduate tutors.

6.1.1 Sequencing and Pacing In Process Synthesis and Equipment Design

At the start of the semester Mr McAvoy gave the students a set of notes for the entire semester as well as a fourth year planner. In his lecturing he followed the notes quite closely which allowed the students the freedom to listen and add notes as they deemed necessary. On the first day of lectures Mr McAvoy introduced the students to what he termed the stages in a design process.

1. Conception and definition
2. Flowsheet development
3. Design of equipment
4. Economic analysis
5. Optimization

6. Reporting

The course contents as detailed on the year planner were sequenced according to these stages. Mr McAvoy therefore strongly controlled the sequence of contents in the course and the students had no say in this. As such the framing was strong with respect to sequencing.

In his email communication Mr McAvoy noted that the approach to Process Synthesis and Equipment Design involved aligning the projects in the course with the Capstone Design Project. To this end the students were expected to complete three projects in the course, all of which were about the design of an aspect of the Ammonia Plant which was the topic for the Capstone Design Project. The first project covered process synthesis and the design report. In this project the students were evaluated on the first two stages, conception and definition, as well as flowsheet development. Mr McAvoy gave the students the project brief on the last day of his round of lectures. Mr Denver resumed the lecturing dealing with the simulation aspect of design during which time the students worked on project one.

In the second project the students were required to simulate a process flowsheet using the simulation package ASPEN. Mr Denver gave the brief to the students at the end of his week of lecturing. During this week, which was the third week of the semester, he also gave students three competency tests on the computer programme used. The students were given three chances to pass the test. At the end of the third week the students submitted project one which means they had just over a week in which to complete it. At the time of submitting project one, they received the brief for the second project and were allowed to work on the second project on the fourth week during the lecture and tutorial slots. The second project was due at the end of that fourth week of lectures. This means they had just over a week to complete project two. Mr McAvoy then resumed his lecturing from week 5 to week 6. Please refer to Appendix C for the full lecturing schedule for the first semester of Year 2.

At the end of week 9, project three was handed out to the students. Project three was about equipment heuristics as well as control philosophy. It required students to do equipment design and economic analysis, stages four and five of the design process, but also assessed material from project one and two. It was thus the culmination of all the material the students had been lectured on in Process Synthesis and Equipment Design. Unlike the first two projects, project three was done in groups. They worked on this project through week 10 during the lecture slots as well as during the tutorial slots and like the other two projects had to complete it in just over a week. The project was due at the end of week 10 which signaled the end of Process Synthesis and Equipment Design lectures. Weeks 11, 12 and 13 were devoted to the other three courses in the fourth year schedule.

The information indicates that in the lecturing Mr McAvoy and Mr Denver adopted the model of intensive blocks of lecturing which were followed by assignments. This happened in three cycles with each cycle covering an aspect of the design stage as noted in points 1 to 6 on page 116. These details are a clear indication that both Mr McAvoy and Mr Denver had very strong control over the pacing. The students had a week in which to complete each of the three projects. In the second project the students had three opportunities to take the computer programme competency tests and had a week in which to come to terms with the ASPEN. Only after the competency tests were completed did the students receive the project brief. In this way Mr Denver verified that by the time the students were required to use ASPEN in the project, they had all had an opportunity to be fully competent in working with the programme. The framing over pacing was therefore strong for Process Synthesis and Equipment Design.

6.1.2 The Evaluative Criteria in Process Synthesis and Equipment Design

To gauge the extent to which Mr McAvoy made evaluative criteria explicit, both his practice in terms of lectures and his feedback to the students were the focus. As was the case in the previous chapter, in observing classroom practice I was interested in the ways in which Mr McAvoy communicated to the students what was expected of them and how

he clarified concepts. In students' texts I was also interested in how he communicated to the students what was missing from their text production.

The material in Process Synthesis and Equipment Design was based mostly on heuristics. In other words, students were taught rules of thumb, in stepwise fashion, applicable in process synthesis as well as in equipment design. The students were cautioned that while the rules were based on experience and apply in general, they should be tested to ensure that they apply in the specific application. They were also told that heuristics were used in preliminary synthesis to generate alternatives and that this process should then be followed by mass and energy balances and other forms of analysis using simulation in order to improve upon the heuristics.

The lectures in process synthesis followed the lecture notes very closely. The only occasions when Mr McAvoy deviated from the notes was to show students videos of disasters by engineers who had made some specific mistakes in design. This was always used as a way to illustrate a point after he had discussed it in class. This was well received by the students and this was observed as students sat up in their seats with all eyes glued to the screen for that part of the lecture. There were occasions when students asked questions during the lecture which he would then repeat and address his answer to everyone. Usually these were to clarify a section in the notes that he was covering. One such lecture was about process flowsheet development and evolution, and he was describing to the students what was involved in the synthesis of chemical plants. According to the notes which he was reading out loud, the first step was about the selection of processing mode, in other words whether the process would be run as a continuous process or in batch mode. At this point one student wanted to know how to make that choice or which was better. His response, which was directed to the entire class, was that this decision depended largely on the expense of raw materials, the scale of the process and the product. He then said that continuous plants were more popular than batch plants. The decisions about whether processes should be continuous or batch were outlined in the lecture notes.

On other occasions he clarified a number of things in the notes without any prompting from the students. Another time some students next to me were a couple of lines ahead of him in the notes under the section called 'synthesis steps'. One student asked the other what 'eliminate differences in molecular types' and 'eliminate differences in composition' meant. These were steps one and three respectively. The other student indicated that she did not know. The students didn't ask Mr McAvoy the question but not long after this, Mr McAvoy explained to the class that 'eliminate differences in molecular type' referred to chemical reactions and 'eliminate differences in composition' referred to separations. There was an audible 'oh' in the class after this explanation. In this case he was clarifying to the students what these synthesis steps meant. This was arguably quite important for the students to know if they were going to be able to follow the different steps.

Mr McAvoy is an experienced engineer with a number of years of experience as a professional engineer. Throughout his lecturing he attempted to bring some of his own experiences as a young engineer into the lecture. It was mostly these references to his experience that appeared to hold the students' interest in lectures. Some of this experience was not captured in his lecture notes but the notes served to prompt some of his recollections. One issue that the students struggled with was that the notes were not indexed in any way. This made it difficult to locate sections in the book. This was exacerbated by the fact that the notes were a mixture of his writing as well chapters on the same material from different textbooks.

Given that some of the decisions that students were expected to make in process design involved decisions about choice of process, i.e. whether batch or continuous, about what not to do in plant layout as well as showing the repercussions of bad decisions, it may be argued that in his lectures Mr McAvoy made efforts towards making criteria explicit.

6.1.3 The Evaluative Criteria in the Feedback

The issue of feedback and the difference it makes in helping students produce legitimate text was an important theme with these students in Year 1 as was discussed in the previous chapter. The poor feedback and the lack thereof formed the subject of most students' deliberations. Unlike in the Third Year Design Project, students received feedback for project one in time to use it in project three. Project two was a stand-alone project but was also returned to the students in time for them to use it in project three.

The same theme was pursued again this year in particular since the fourth year lecturer's forum wanted the process synthesis course to be assessed with the requirements of the Capstone Design Project in mind. To get a sense of the feedback in Process Synthesis and Equipment Design, I asked the students about the feedback received from each of the projects. Attention was given not only to what they said about the feedback but also to any emotionality associated with their responses. This is again in line with how their responses were dealt with in the previous chapter.

In general, it seems that the students were distressed by project one as most did not seem to have known what to do or did not know what was expected of them. Some of them attributed this to the fact that a tutorial that was supposed to have been used as a 'dry run' for project one was only done after the project had been submitted, indicating a sequencing problem. Moreover, a very basic mark allocation sheet was given to the students which attributed certain marks to certain sections in the report. This, however, did not necessary clarify to the students what was expected of them.

> *The problem we've had is that we think he hasn't told us what to do before and then he gives all this feedback afterwards to tell us what we should have done but he never really told us before…*
> *(Brian, Interview)*

According to Brian, Mr McAvoy was not clear about what he expected of the students in project one. This was exacerbated by the sequencing issue which meant the tutorial that was meant to clarify issues for the students was not given to the students. On returning their scripts it seems there was some detail in the feedback about what the students

should have done. While Mr McAvoy did not give too much detail on the scripts, he was able to handle most student concerns regarding project one through the mark sheet given once the projects had been returned, through the lecture that he then held, as well as through the emailed feedback. While this was an attempt at rectifying the sequencing issue, it was a source of frustration for the students whose marks were negatively affected by this. Mike refers to this below.

> *But you also don't get told that… they want you to comment on this and this and this but you don't get taught to comment on it. I think it's also quite harsh that marks (are) assigned to that, (for) project one ten marks for design basis or something but nowhere did it say give a design basis, so like most of the class just didn't do it and you would easily get those ten marks.*
>
> *(Mike, Interview)*

Mike points to the issue of not being taught how to comment on material but being expected to do so. He sees it as unjust to then lose marks for not including something which you were not asked to include. It seems that, according to him, he was not necessarily able to produce legitimate text in project one because the criteria were not explicit. Devon is also concerned that he is not being directed towards legitimate text specifically enough.

> *I think the biggest worry is not knowing exactly what they want … I mean they want mass balances…but what (do) they want you to pick up on? And then maybe I think they could; they need to say, 'Discuss why this conversion is this'…they could direct you into looking at certain aspects of certain things in more detail…* *(Devon, Interview)*

Thus it seems the lecturer expected students to focus on and to comment specifically on certain aspects in the report which most students did not do, hence the generally low marks for project one. Part of the issue as they see it was that the mark breakdown given to them before the project was not detailed enough for what he apparently expected of them. These issues were addressed however in the feedback session after the project was returned to the students. Therefore, while there was an attempt in the course to make criteria explicit, the poor sequencing was a source of frustration for the students as it resulted in low marks.

Mr McAvoy provided a detailed feedback sheet after project one which meant the students had a better idea of what to include in project three. In response to the students' experience of project one, he provided a mark allocation sheet, along with the project statement for project three. This included quite a bit of detail with marks allocated to sections and subsections. The detail was such that the total mark allocated for project three was over 500 marks. Mr McAvoy also gave detailed feedback for project three in the form of a report. In the report he included his impressions on the project overall, followed by some detail on what the students did and what they should have done in each section. This was another way Mr McAvoy made criteria explicit.

Mr Denver provided detailed feedback for project two. The structuring of his project and the mark allocation sheet are included in Appendix E for reference. He allowed students three attempts at the competency test before they started with project two. This suggests that most students felt that the detailed feedback from projects one and two helped them in project three as they were then in a position to incorporate all the ideas given to them in the feedback. Therefore, the framing over evaluative criteria was strong.

6.1.4 Hierarchical Rules in Student-Lecturer Relations

Over and above issues relating to *the instructional* in Mr McAvoy's practice, another issue that emerged was related to how he was perceived as a lecturer by the students and about the perceived boundaries that existed between him and the students. In general he was perceived as a good teacher and as approachable. The first two extracts refer to his feedback but also to his teaching in general.

> *Mr McAvoy's a very good lecturer, he's a bit chilled….which I like (it) makes me calmer, I like the way he relates stuff. Sometimes I wish he had page numbers in his book so I actually know where his stuff is. But in general he's a very good lecturer… (Kathleen, Interview)*

> *Mr McAvoy has good experiences. He can draw from his own life experiences and he's shared some of them with us. And he teaches well and he makes things clear…he's approachable. We talked to him a lot and he talked to us about a lot of stuff like the pump situation. He's quite; he knows a lot and he's approachable… (Brian, Interview)*

This last extract refers to the wealth of knowledge that Mr McAvoy possesses in terms of his industry experience. He referred to this experience quite frequently in his lectures and some of the students, as seen in some of the extracts, enjoyed his banter about his 'life as an engineer'. Part of this approachability was due to the fact Mr McAvoy was quite happy to field complaints by students on the assessment. It is possible that part of this was due to the student experiences in project one. Some of the students felt that even though general performance in project one was poor, Mr McAvoy took this into consideration in his marking.

His approachability seemed to define what sort of conduct was appropriate within the student-lecturer relation. It seemed to give some students the freedom to enter into negotiations over the marks with him.

> *I do have a tiny problem with project one ... there were a lot of people who complained about their mark. Now I understand that can happen, it happened in project two as well, but I think Mr Denver handled it very professionally. He said 'If you have a problem email me, put it in writing I'll remark it'. With project one it was more like if I attack you long enough then I'll eventually get you to give me an extra percent. I think some lecturers open themselves up to that. They start a very bad chain reaction. I think you need to be consistent as to who you're talking to because the more aggressive people in the class, who are not afraid to scream and shout and attack a lecturer [and they exist], do that. In my opinion it's just a basic lack of respect but they get their mark raised. Whereas somebody whose approach is 'Will you please explain?' will not get that and so a small problem with Mr McAvoy is that I think he opened himself up to have a very casual relationship with us and then people exploited that.*
>
> *(Tanya, Interview)*

This extract illustrates the shift in the relations of control between the lecturer and the students from strongly framed (positional), to weakly framed (personal). The issue of the shift in relations of control was observed in the spatial arrangement of students in the lecture theatre. White students tended to occupy the first few rows with the black students occupying the rest. This meant white students could ask Mr McAvoy a 'quick' question and carry on a conversation with him from their seat.

In relating to all students Mr McAvoy would have been aware of his position of power in the relation. However his 'chilled' and 'laid back' manner changed the power dynamics so that the relation was between individuals as opposed to a lecturer and a student. This

meant the power relations were temporarily disguised thus allowing these students options in that relation, such as negotiating marks. The notion of students being able to change their own personal circumstances in terms of marks by approaching lecturers was another theme that emerged when the students were in third year. Interestingly, Tanya, who brings it up in Year 2, is one of those who approached a lecturer for her mark to be raised in Year 1. It seems the difference this time however is that while in Year 1 the lecturer came across as negligent and unapproachable, Mr McAvoy's practice exhibits more structure and less chaos. But he was seen by the students as 'chilled' and as such 'opened himself up to having a casual relationship with students' which some felt was then exploited. One other student made reference to this where he and a group of his friends also visited Mr McAvoy with the intention of having marks raised for reasons they thought were legitimate.

In light of students' stated concerns, which ranged from completing the degree, completing it in four years, to finishing with first class honours, getting the 'right sorts' of marks was crucial and some students were prepared to 'fight' for these. Mr McAvoy's approachability also meant students felt they were able to 'just drop in' to see and speak to him about the projects thus relating to him as an individual as opposed to a lecturer in a position of power.

> *Although his office not in the chemical engineering building and everybody is lazy to go there, I normally…pop in and tell him 'I'm having a problem with this and that' and he'd say 'Okay Tariq I'm a bit busy now can you come back tomorrow'. On some days he'd even help me but he was very approachable…* *(Tariq, Interview)*

The relation between weak framing in the regulative, i.e. over hierarchical rules, and strong framing over evaluative criteria had been previously described by Morais et al., (2002) as favourable for some students for producing legitimate text and therefore for learning. No such claims are being made at this point as successful negotiation over marks with a lecturer does not give information about a student's ability to produce legitimate text.

6.2 Student Deliberations

The following section gives further detail about what students deliberated over. Again these were the things that the students felt made a difference to their realising their stated concern. These were the nature of the allocated design group, the time allocated to each project, the time pressure and the inferring of realisation rules.

6.2.1 The Notion of 'Luck and Fortune' – The Good Group

In putting together the proposal for an integrated fourth year, the programme committee argued for a focus to be placed on examination by projects. They did acknowledge however that this mode of assessment, given its reliance on groupwork, was potentially problematic. Despite these reservations however, the assessment tasks were run as group projects in the core courses in fourth year. Some sections in the Capstone Design Project were also assessed as group projects. In Process Synthesis and Equipment Design, project three was a group project while projects one and two were individual projects. Given this emphasis on projects by groupwork, I asked students to talk about their groupwork experiences.

Several themes that pertain to groupwork emerged. The first one which some students alluded to in Year 1 was around the notion of the 'good group'. In other words a number of students felt very fortunate and lucky to have 'landed' a good group. These students often had very different experiences of project three compared to those who were not 'so lucky'. The associated stress levels were also different.

> *I think that wasn't too bad, the third project I mean. I think it boils down to your group and I think I was fortunate to have a good group with various expertise. One person was very good with calculations and he got very good marks last year I think. He tackled the ASPEN. Another person who was very good with Microsoft Word basically edited our whole report, put in the contents page, put in the page numbers. (It was) very professional… (Tariq, Interview)*

The students defined a good group as one in which the members had the same expectations of each other, where one member had worked with at least one other member at some point in the past and therefore could relate to them, and where the

members were able to work at the same speeds[26]. The appointment of a leader was also crucial to the functioning of some of the groups. Some students thought themselves 'lucky' if their groups consisted of so called experts in certain areas as determined by their academic records. This made the division of labour within the group less contestable. Moreover, what seemed to make a group work was the way they handled those members of the group who were not able to fulfill the expectations the group had of him or her. It seemed also that people within the class knew each other well enough to be able to tell whether a group would work or not. The groups that did not work were largely due to members who did not participate in any of the processes, meaning that other people had to then bear the extra burden.

6.2.2 Time: Pacing in the Projects

The second issue concerning project three, and groups in particular, was the amount of work relative to the time the students had to complete it, the amount of learning they felt actually happened in that time and the direct benefits in relation to the forthcoming Capstone Design Project that the students felt they derived from project three. These three issues are highlighted in the extracts below.

> *We were working fast, it was just hectic. It was insane the amount of work we had. Even with five people working hard. Last Friday night, because this was for Saturday five o'clock, we didn't go home at all, our whole group…* *(Brian, Interview)*

> *I do think it's overloaded to an unnatural degree, I really do. I don't think it's beneficial to the students, particularly project three. I think the whole project week and doing the project in groups really works well but the volume of work in relation to the time… if there was more time it would be fine…* *(Devon, Interview)*

While the academics in the teaching team saw that it was beneficial for students to experience working in student teams, it seems that the students still felt under some pressure despite being in groups and having the potential to spread the load. They felt the week was not long enough. This somewhat challenges the idea put forward by Prof

26 More often than not the issue of speed was about people's academic strengths. In other words the academically strong students could work faster.

Reed that by introducing students to the design topic in the first semester the students would be able to appreciate flowsheet development in a less time pressured design environment.

6.2.3 Time Pressure and the Acquisition of Realisation Rules

The particular issue with 'time' was how much the students felt they actually learnt over that period as is shown in the following extract.

> *The whole thing of this, is supposed to be like doing the design in the second semester. But there was still a lot of delegating. So if you had a group of four, the first person was doing the utility flow diagrams, the second was doing the ASPEN modeling, the third person was doing the control valves and the control, and the fourth person was doing the environment. Some of the things we had done in project one and two on our own, such as the ASPEN and the flowsheets development. But things like the utilities and the utility flow diagrams and the environmental side and the control side was all new to the project. So people that didn't do that haven't done that now…the people that did control are going to do only control and they're not going know how to do the utilities.*
>
> *(Devon, Interview)*

According to Devon the pressure that the students were under to complete project three in a week was not necessarily warranted given that Process Synthesis and Equipment Design was a learning course meant to prepare the students for the Capstone Design Project. He felt that in order for maximum learning to be achieved the students needed to be given a chance to understand the work by being involved in more of it than what delegating among five or six people allowed, due to time constraints. The delegation did not necessarily allow all group members the opportunity to come to terms with all aspects of the design in project three. This was seen as problematic for the preparation for the Capstone Design Project. He also alludes to the general well-being of the students associated with working for long hours and the effect that had on their ability to think and work efficiently. This sentiment was echoed by most of the students but was also a concern in Year 1.

> *I was lucky because I did a lot in the project. So I learnt about almost everything. But I mean the guy who did the ASPEN spent all his time on the ASPEN, and then had to write up about the ASPEN. And so the sizing of valves, the plant layout, the safety and environment … he did not do. I think that disadvantages you when you come to final design… (Tanya, Interview)*

> *I know myself ... I probably didn't understand a lot of things. But just because we had a time constraint, you can't, if you tell your group, 'Explain this' they'll say, 'No we have a time constraint, I'll explain to you another time'. But that other time never happens …*
>
> *(Tariq, Interview)*

It seems that the students were concerned about their preparedness for the Capstone Design Project after the pressures of project three. Tariq in particular was worried that because the project was highly pressured in terms of time, there were limited opportunities over that week for group members to make sure that all other group members understood everything about the project. Interestingly, while all students were concerned about the 'limited learning' that they received over this period, Tariq and Nolwazi were the only two who explicitly talked about the role played by other students in making sure everyone was on board. According to Tanya, however, it seems that the amount one was able to learn depended to some extent on one's role within the group. Because she was tasked with proof reading, and had done 'a lot' in the project, she was in a position to see the project as a whole and, as she says, to see things she hadn't known about or thought of herself. Thabang alludes to this as well. For him being a group leader meant he had to know everything about the project.

> *I was doing all the technical, hardcore stuff; the number-crunching, ASPEN, all the deep stuff. So it was all that. So people were reporting to me on their progress…I was the one who was working the longest hours because you have to pull your weight, if you are the leader. People are expecting a lot from you so I had to pull weight….* *(Thabang, Interview)*

Apart from the specific technical contents of design in project three and in Process Synthesis and Equipment Design as a whole, some students felt that the course allowed them to experience decision-making under pressure. They felt that due to this they were in a better position to be selective about what was important and required in generating a design report. The following two extracts refer to this.

> *The other courses before Process Synthesis and Equipment Design focus more on the answer, i.e. whether your thing comes out and the shape's right or whatever. I think a lot of people are still stuck in that frame of mind … in the design it is more important that even if it's completely ridiculous, you just say this is completely ridiculous and give the reasons saying, 'If we had more time we could fix it by doing this and this and this'. Rather than spending the entire week sorting out this tiny little thing you just accept that it's wrong and then write your report based on the fact that it's wrong. That's what I figured out in project three. Everyone fiddles around with it for the first part of the week and then rushes for the report and the report is the most important thing. And*

> *you can have complete garbage coming out of ASPEN, but as long as you write the report well and say what the problem is, you're still learning more than the (guy) that's just trying to figure it out. I think that was probably also the difference between project one and project three. You kind of pick up that's the more important part…* *(Mike, Interview)*

> *We had one defining factor, (the reason) why we managed to get our stuff done so well and on time. We said, 'On this day, at this time, whatever our output is for ASPEN, we will accept it and we will work with that' and that's what we did. So our ASPEN probably wasn't perfect, I doubt it. We didn't have all the right reactors in it but that's not the point of project three, ASPEN's not the point…* *(Taryn, Interview)*

In the second extract, Taryn does not necessarily refer to what goes into a design report in the same way as Mike does but her group understood that 'fiddling around', to use Mike's phrase, was not the point of project three. They were able to set limits for themselves in order to have time to generate a good report. As it happened they submitted well in time and were the only group to achieve a first class pass for this project. Therefore it seems some students understood from Process Synthesis and Equipment Design that under time constraints strategic decisions needed to be made about when to stop working and when to start writing the report. Additionally, they needed to then be strategic about what to include in the design report in order to generate a legitimate piece of design text.

6.3 Evaluative Criteria Revisited – Workload

The issues regarding time and how much the students learnt in the pressurised environment raised questions both about the overall workload for project three and the evaluative criteria and general preparedness for the Capstone Design Project.

> *From what I understand about this year, Mr Denver has been saying, 'Oh my goodness the third project has just been completely over board' but then Mr McAvoy was also saying, 'You know last year after having Chemical Engineering Design the students said they weren't prepared for Chemical Engineering Design and that project three should have been, they should have been allowed to maybe be thrown more in the deep end in the first semester'. So I don't know if that's they were going for.* *(Kelly, Interview)*

In this extract Kelly refers to the perceived difference in views between the lecturers of Process Synthesis and Equipment Design regarding the workload in the third project. It seems that Mr Denver, who was in charge of only project two, was of the opinion that

project three was overloaded. Mr McAvoy, on the other hand, according to Kelly's extract, felt that this was justified as previous students had felt less prepared for the Capstone Design Project. Mr Denver in the extract below confirmed his views on project three, not only about the workload but about what the focus of project three should have been in Year 2.1 and what Process Synthesis and Equipment Design should be assessing in general.

> *I thought project three was too long, overloaded…My view on these projects is that you are not trying to assess whether the students can do the same thing a hundred times but rather can they think through and justify what they are doing. So, while the nature of design is that it does involve some repetition (and thus it IS an important part of Project three to develop and assess student-teams' ability to allocate and perform tasks based on repetitious activities, e.g. set up equipment lists based on shortcut sizing and costing of pumps and Higher Education's, etc.), you should rather reduce the size of the overall process and explicitly allocate some of the assessment to "thinking" (e.g. discussions of how changes in the process would affect economics, etc.)…*
>
> *(Mr Denver, Email communication)*

Mr Denver's extract points to two issues. Firstly he confirms what was said earlier by Mike regarding some students' inability to recognize what is important in design and therefore what they should be spending time on. While Mike refers to ASPEN and the fixation upon little things that some students tend to have, Mr Denver refers to repetitive procedures which, although they have their place, should not be the only focus. The point being made by Mr Denver is that there should be a balance between the 'little' tasks or the repetitive work and the equally more important work in design which is the thinking and the discussion of key issues about the process itself. Secondly, Mr Denver believes that project three was overloaded and should have focused the assessment more towards tasks which encourage students to think and reflect. He refers to this in the following extract where he also makes specific recommendations about how project three should be run.

> *Before Process Synthesis and Equipment Design was given back to Prof Alcock, I had several meetings with Mr McAvoy to discuss how to run the course in future years. In Year 2, I just let Mr McAvoy run it as he always had…So as not to overload Project three, we also talked about handing out the mass/energy balance several weeks before (i.e. straight after Project 2), and then having a preliminary hand-in marked by tutors, so that, during the Project 3 block week, the students would not get bogged down with this, but could concentrate on the real outcomes of that project ...*
>
> *(Mr Denver, Email communication)*

Handing out the mass and energy balance sections earlier would have lengthened the project and thus changed the pacing. This would have allowed for some of the grappling with the problem that some students referred to in the interviews instead of the 'churning it out' that they felt actually happened. The mark sheet provided by Mr McAvoy for project three which detailed the mark allocation for each section (see Appendix F), does not appear to have challenged the students to reflect on how changes would affect other aspects such as economics. The feedback that he gave after marking the scripts did not necessarily give recommendations on this issue either as it was not a specific requirement for him. Rather, it was in line with the marking allocation sheet that he had given out with the project brief.

Therefore, while the framing was described as strong with respect to evaluative criteria, it seems that it is not necessarily clear among academics involved in Process Synthesis and Equipment Design what the evaluative rules are, i.e. what the students should actually be assessed on in this design. This calls to question the strength of the framing over evaluative criteria. As far as the 'real outcomes of the project' that Mr Denver refers to above, they do not appear on any of the project documentation. There are, however, course outcomes in the course handout which do not make explicit reference to the kind of thinking that Mr Denver refers to in his extract.

6.4 Student Deliberations – Modes of Reflexivity

According to the preceding evidence, the Process Synthesis and Equipment Design course was a demanding experience for the students. Each of the projects had aspects to it that defined the experience differently for different students. There were some who were particularly exasperated by some of the issues raised for several reasons that will be explored. These cases have been highlighted because they give an idea of the sources of anxiety for the students. This does not imply that those students who did not mention these things in the interviews do not also have areas of concern. But in light of students' stated concerns and given the conditions they were all under and were about to face in

the design project, the peculiarities in the reflexive deliberations of each of these cases need to be noted.

6.4.1 Project One - Rules Pertaining To Text Production

Nandi was particularly distressed about not knowing which section of the notes to go to in order to start with project one.

> *We did project one and then I remember we were asking, 'So what do we do, like one to five, one to eight, just this section or that section?', he just said 'I want to see it evolve'. If I was also in his shoes I can see what he's saying, 'Learn'. But at this stage of the degree we do not have the luxury of learning. When it is your marks that are on the line in December, no one is going to know that I learnt. They're going to know that I passed… (Nandi, Interview)*

Nandi seems to make a distinction between what is more important 'at this stage of the degree', i.e. in fourth year. She concludes that passing is more important and that learning is a luxury which she cannot afford. In her view, expectations must be communicated clearly, i.e. 'do steps one to five or one to eight' etc., so that presumably she knows what to do, does it and passes. In a separate interview she was also distressed about the lecturer's insistence on correct referencing. It was her contention that while referencing is important her frame of mind is that as long as the technical side of things is done correctly then she is okay. She is again defining for herself what is important. This is distinctive largely because most of the other students appeared to enjoy the opportunity to learn at this level despite the pressure. Overall they were positive about wanting to learn but were unhappy that they were perhaps not given enough time. Nandi again refers to project one and characterizes it as the biggest jump 'they' have had to make this year.

> *Project one was the process of flowsheet development. It is quite long and you need direction from when you start. You can't start and then find out later that you needed to do mass balance. Something that took us days last year is assigned a few hours (this year). In his mind he thinks that should be enough. Every year in chemical engineering you're supposed to jump, but this was the highest jump. We had to adjust to quite a lot… (Nandi, Interview)*

In her view prior to fourth year they had quite 'a bit' of time to devote to mass balancing etc. but this year she felt Mr McAvoy expected them to do it in a day which for her was a

high expectation. Nandi came across as a loner. This was partly due to the fact that she was a year ahead of the other students and as such did not have strong affinity relations with others in this class. On some level this meant she deliberated autonomously.

Nolwazi talks about how she would not have been able to finish project one on her own.

> *We were, I was working with people, you still did that. I still did work with people. I don't think I would have finished it if I was just doing it by myself….* *(Nolwazi, Interview)*

Nolwazi displays communicative reflexive tendencies. Project one was an individual project and, given the general uncertainties in the class at the start and during the project, it is perhaps not a surprise that students would have used each other as a resource in order to begin working on the project. This suggests therefore that even some autonomous reflexives would have been inclined to communicate in order to work through the uncertainties. What is distinctive about Nolwazi however is that she feels she would not have been able to finish it on her own indicating quite a strong reliance on her peers to complete the task. Other students acknowledge having had consultations on specific things and some talked through the detail of what their strategies were in grappling with starting project one. Kathleen is one example.

> *I didn't really understand what we were supposed to be doing. I knew that we had to make an ammonia plant but, how would I make it …I focused on each point separately. I started out with, I knew how to get nitrogen then I was left with methane to hydrogen. And I said to myself, 'Oh my word how do you do that?', and then I said to myself 'Okay there are several methods'. Then I looked at the hydrogen method and I looked at steam reforming, the partial oxidation. By then everybody had started on their mass balance already and I said to myself 'Okay this is the second day I'm quite far behind'. Then everybody was doing steam reforming first then partial oxidation. I said to myself, 'Why not just do partial oxidation?' Then I looked at the different methods, all the methods like steam reforming, partial oxidation and also carbon reforming as well. I looked at all of them and I didn't know which ones to choose. I said to myself 'Oh my word okay let me just do what everyone else is doing', I looked at all of the methods…*
>
> *(Kathleen, Interview)*

Kathleen talks about what she was grappling with in terms of trying to develop the flowsheet. She indicates that she was aware of what other people were doing around her and could sense that she was slightly behind but throughout this phase she gives a sense of having been in charge all the way to completion, thus managing to finish on her own.

At the end of the extract she notes however that she did not have the criteria to make the correct choices for some of the equipment and ended up doing what everyone else was doing. Later on she mentions that her final submission was not great but that was the case with most of the students for project one under the circumstances. Therefore Kathleen tended towards autonomous reflexivity, a tendency which does not appear to have been affected by uncertainties in her environment.

In the previous chapter Nolwazi's interviews also flagged her dependence on her peers where she spoke at length about 'needing to work with people', i.e. that working with people was a non-negotiable and that one cannot 'do it on their own'. Tariq was flagged in the previous chapter as one who tended to look to students who 'get higher marks' for help. This trend continued here. Kathleen is quite the opposite and even in the third year design went to great lengths to grapple with issues on her own in getting tasks done. What is starting to emerge then with this group of students are the different modes of reflexivity. It seems there are communicative reflexives within the group, such as Nolwazi, as well as autonomous reflexives such as Tanya and Kathleen. Table 7 provides details of the students' different ways of working in the Process Synthesis and Equipment Design context. This continues the reflexivity conversation started in the Third Year Design Project. The mark provided is the final mark for the entire course.

Table 7: The use of resources in the Process Synthesis and Equipment Design context

Student	Population group	Preferred approach towards the use of resources	Approach adopted in this context[27]	Process Synthesis and Equipment Design marks
Brian	White	Works with girl friend or alone	Worked alone and consciously chose a different route to everyone else with success.	75
Devon	White	Prefers to work alone	Worked alone for project 1 and felt others were too slow in the group aspects	70
Gontso	Black	Prefers to work with friends	Worked alone for project one enjoyed being in control of all aspects of the work	61
Kathleen	Chinese	Prefers to work alone	Worked alone	55
Katleho	Black	Starts off on his own in general	Had to consult friends	61
Kelly	White	Works with Mike	Worked with Mike	69
Mike	White	Prefers to work alone	Worked alone	74
Nandi	Black	Prefers to work alone	Worked alone	60
Nazlee	Coloured	Works with friends	Worked with friends	63
Nolwazi	Black	Prefers to work with friends	Worked with friends, declared she would not have finished on her own.	67
Petrus	Black	Works alone	Consulted with friends	60
Tanya	Coloured	Works alone	Worked alone	73
Tariq	Indian	Prefers to work with others (not necessarily friends)	Worked with others	61
Taryn	White	Prefers to work alone	Consulted with friends	66
Tasneem	Coloured	Preferred to work with friends	Worked with friends	62
Thabang	Black	Prefers to work alone	Worked alone	62
Zunaid	Indian	Prefers to work alone	Consulted with friends	74

The table indicates that some students, such as Gontso, started to move towards being autonomous. In the third year context she declared that working with people was the only way.

6.5 Conclusion and Looking Ahead

This chapter presented the second phase of a three part interaction phase in the morphogenetic sequence which started in July of Year 1 and concluded in September of

27 This is the approach to project one, the individual project.

Year 2. At the start of the first interaction phase (in the third year) the students were introduced to design through a design project which aimed to highlight the design-related aspects of two of their core courses. The most pertinent finding relating to this first interaction phase is that a combination of factors created situational imports for the students, potentially putting at risk their efforts towards acquiring the realisation rules. These factors were strong control over pacing in the design project and strong classification of agents (the lecturers) between the two core courses and the design project. They resulted in weak sequencing of the contents among the three areas. These factors combined to give a practice that was weakly framed in terms of evaluative criteria. The implication is that the students were not necessarily provided with adequate opportunities for learning design. They dealt with this in different ways including the exercise of agency, collective and individual, and by exploiting the relations that existed in the student group, with various levels of success. At the end of this period five students failed the project (Refer to Appendix D for the full results of the Third Year Design Project marks). However, due to the weak framing over the evaluative criteria it was unclear whether the students who passed had acquired the realisation rules. In particular, at the end of this period there was a general question as to whether the students had acquired the basics on which Process Synthesis and Equipment Design, presented in this chapter, would have to build.

When they entered fourth year, the system was quite different in a number of ways. The entire system in the first semester of fourth year was founded on the idea of integration which aimed to add considerations of economics, entrepreneurship, macro process design, process control, optimisation and communication to the students' growing understanding of design. This new phase introduced students to the idea of process systems, removing them from the detail of individual pieces of equipment and asking them to consider a range of other macroscopic factors in design. Process Synthesis and Equipment Design was the course of interest intended to prepare students for the Capstone Design Project.

Upon closer inspection however it seems the benefits reaped by the students of this integrated approach are not necessarily obvious. The students appeared to have been under intense pressure particularly during the week of project three. Due to this some felt unsure about the learning that happened in Process Synthesis and Equipment Design, particularly given that it was a course meant to prepare them for the Capstone Design Project. The other lecturer involved in Process Synthesis and Equipment Design was of the opinion that project three was unnecessarily overloaded and focused too much on repetitive design tasks and not enough on other equally important design tasks, i.e. thinking and reflection. It seems therefore that while the agents were sufficiently weakly classified to have created an integrated structure in terms of the timetable at least and the structuring of lectures, it is questionable whether that same integration existed at the level of ideas informing what the evaluative rules in design should be.

The full implications of this become evident in the following chapter. It is clear at this stage that some students dealt better with the pressures and demands of Process Synthesis and Equipment Design, and project three in particular, than others

Chapter 7
The Capstone Design Project

This chapter presents the social interaction during the Capstone Design Project. In Chapter 1 the issue of the high failure rates in this course was raised, in particular the issue of the failing students being from a designated group. As part of investigating these issues it was hypothesized that something could be going wrong before the Capstone Design Project in the students' design education. The previous two chapters provided the details of the social interaction in the design contexts for this cohort from Year 1 July to Year 2 June. It was also hypothesized that something could be wrong with the Capstone Design Project itself. This chapter will therefore provide some detail of the social interaction in this context. As was the case in the previous two contexts the first part of the chapter focuses on the nature of the pedagogic practices (the student/lecture relations) in the Capstone Design Project and whether any aspects of it were found to be constraining or enabling for the students. The second part of the chapter focuses on how the students deliberated over these situations in the Capstone Design Project towards realising their project of passing the course and then graduating.

In considering the range of different interactions that created situational imports for students in the context of the Capstone Design Project, the concerns and situational logics that they defined issues in Chapter 5 will be considered to be relevant in this context as well. In this way having understood the students in Chapter 5, their actions in the Capstone Design Project will be considered in light of that information.

Therefore I was interested to establish whether the students approached the constraining situations in the same manner as in the previous two contexts and if so whether they achieved success as a result.

7.1 Pedagogic Practices

In keeping with Prof Reed's idea of pointing students in the right direction during the design and thus adding a formative component to the course, he arranged oral presentation sessions. The purpose was to evaluate the students' preliminary submissions and then to meet the students individually within their groups to discuss those initial efforts. After these oral sessions the students were then supposed to take all recommendations made by Prof Reed on their work and incorporate them in their final submissions. This procedure happened twice; once for mass and energy balance submissions and once for unit design submissions. After each round of oral presentations Prof Reed met with the whole class to give final general feedback and to address any questions that the students had.

The term was structured over weekly and fortnightly blocks with students expected to submit at certain intervals (This information is available in Appendix D). The framing over the pacing was therefore controlled by Prof Reed. In particular, between the oral presentations and the final reports the students were expected to use that time to fix their errors and then to submit the final reports for mass and energy balances and unit designs.

7.1.1 Evaluative Criteria in Feedback Sessions

In order to have a sense of how Prof Reed made criteria for evaluation explicit and to then find out how each of the students in the sample dealt with the feedback given to them, I observed the interviews for all fifteen groups as the students in my sample were spread out through all the groups. Each group had between five and six students and the same question was posed by Prof Reed to each student initially: 'What was your objective for the unit, how did you design it?' From then on the nature of the conversation depended on each student's response to the initial question.

It was clear during the oral presentations that not all the students had progressed to the same level. A conversation which typifies how Prof Reed handled the feedback sessions is

shown below. What is significant at this stage is not so much who the student was but rather the nature of this exchange and the detail that Prof Reed sought. Therefore, instead of providing the name of the student involved I have left it as 'student'. Even though the questions were always addressed to one student in the group, Prof Reed allowed other students to contribute especially when it seemed that the student being questioned was not able to give a satisfactory response.

Prof Reed: Tell me how you designed your water-gas shift unit. What were your objectives of the unit; how did you go about designing it? *(line 1)*

Student1: Okay, the objective. I thought it was; I needed to produce the amount of CO_2 in our process. So the way I did it… *(line 2)*

Prof Reed: CO_2? *(line 3)*

Student1: CO, carbon monoxide. For the HTF and the LTF they gave outlet compositions for the carbon dioxide, carbon monoxide coming out. So what I did was I based my conversions for the CO coming in and then I changed them so that I meet the composition they gave me. So I did that for both the HTS and LTS. *(line 4)*

Prof Reed: Okay what are the objectives of the reformer plus the water gas shift? What are the objectives? *(line 5)*

Student1: The reformers give you hydrogen. You want to generate, the reformer gives you hydrogen. We want to generate hydrogen for the ammonia process. *(line 6)*

Prof Reed: No they give you hydrogen, CO, CO_2. There's water in the stream, there's Nitrogen in the stream. So what are the objectives of the reformer plus the water gas shift? *(line 7)*

Student2: Don't you want to get your 3:1 stoichiometric ratio of hydrogen to nitrogen? *(line 8)*

Prof Reed: So a 3:1 hydrogen to nitrogen ratio. That's the objective. You get this out of your reformer section. You get a hydrogen plus CO and nitrogen of slightly above 3. Now your shift reactors convert the CO and the water to hydrogen. How did you go about this; how did you decide which or what conversion you're going to have for the high temperature shift or for the low temperature shift? *(line 9)*

Students1: Oh the conversion, I just used the compositions I was given in literature and then changed the conversion so that I meet that conversion. For the hydrogen to nitrogen ratio I used the amount of air coming in.

(line10).

Prof Reed: Ok? *(line 11)*

Student1T: I used the amount of air coming in to meet the spec…I ensured that I had a 3:1 ratio just before I getting into my Haber process not before, not after the shift reaction. I just made sure that

just before the reactor there was a 3:1 ratio. I didn't consider it for the other unit. *(line 12)*

Prof Reed: So you're saying you want to have your carbon monoxide concentration at the exit of your water gas shift to be 0.3. Why 0.3? *(line 13)*

Student1 :……(no response from him)… *(line 14)*

Prof Reed: Okay I know you've written here that it's suggested by Nihaud, but why 0.3, why not 0.2, or 0.4? *(line 15)*

Student1: Okay I thought it is probably low enough because we want to reduce the amount of carbon monoxide being processed and since we're going to have it react with that to produce the CO in situ, I thought by reducing it to 0.3 we make sure that we don't use so much and end up losing it… *(line 16)*

Prof Reed: Let's go back a bit now…so I'm still thinking about constraints in the design and design variables. Now is this 0.3 percent carbon monoxide in the product stream a design variable or is it a design constraint? *(line 17)*

Student1: I think it depends on what you're trying to achieve, I think it might be a design variable… *(line 18)*

Prof Reed: It could be a design variable I agree. I don't think it's the most useful design variable… How am I going to find out whether this is an optimum process or just a process? Now you concentrate on the water gas shift but in principle, it's all the units. Look at the units and see what are the constraints that you have to meet, and what are the design variables. It's a general comment by the way. I didn't see any design variables. You've got to find a way of optimising the design. *(line 19)*

Student3: Sorry I've been optimizing…and experiencing problems…. *(line 20)*

Prof Reed: What you need to do is have a set of five or ten variables. So vary one and see how the process changes keeping other design variables constant…vary them systematically….and try to find an optimum design. What's an optimum design? Minimum energy; minimum flowrates; minimum velocity. *(line 21)*

In this example, Prof Reed elicits from the student the methodology behind the design of the water gas shift unit by asking about the objectives of that unit (line 1). The student gives a response to this which does not seem to satisfy Prof Reed. However, Prof Reed uses the student's inaccurate response to ask another question related to the objectives of the reformer unit which precedes the water gas shift unit (line 5). The student does not answer this question satisfactorily either and a second student offers a response. The response from the second student is the correct one as is indicated by Prof Reed's own response (line 9). Once the objectives of the reformer are established Prof Reed then

goes back to his original question about the objectives of the water gas shift unit and gives the correct response himself. After this he probes further regarding the specific decisions the student made regarding certain design parameters for the water gas shift unit. It emerges that the student made some choices, i.e. used values from literature but did not have a good reason why those values were valid. From here Prof Reef makes a point to distinguish between constraints and variables in the process of achieving an optimum design. He tells them not to look at just one unit but to look at all the units and to define constraints and variables for each (line 19). In line 19 he points out that none of the students in the class had paid enough attention to this issue. A third student points out that he had tried to get an optimum process but had experienced some problems. At this point Prof Reed then tells them what they must do to optimize and gives the characteristics of an optimum design (line 21). This point was stressed by Prof Reed after every single oral presentation even if not all students had raised this particular issue.

Other issues that were highlighted in other conversations had to do with language use in report writing. A number of students wrote what Prof Reed termed 'imprecise statements', such as the two below which appeared on a student's report.

> *This is due to the lowest methane which enters the column.*
>
> *This section of the plant removes all of the H_2S and some of the CO_2.*

Prof Reed read these out loud during the session and his response was:

> *I'm just saying these kinds of imprecise statements are not on; you're a chemical engineer; I won't have it.*

Prof Reed went on to say that the students needed to use real percentages. He specifically positioned the students as chemical engineers in this instance and used that emphasis to support his point. As chemical engineers, they were not allowed to use soft language as the discipline, derived from the 'hard sciences', required precision in communication. This precision extended beyond words to include drawings and 'stream' tables as well as the content of different sections of the report.

Furthermore, some students had not included certain sections in their preliminary reports. During the oral feedback session Prof Reed's approach was to tell the student that upon reading the report he noticed that some things were missing and then invited the student to talk about how they planned to address whatever section it was that they had not included. Again, these conversations were typically characterized by probing and leading questions where it was obvious that the student did not know what to say. Here again other students contributed and again the sessions ended with Prof Reed telling the student how to approach that section.

The foregoing has been an illustration of Prof Reed's attempts to make evaluative criteria explicit. These were strengthened by the fact that Prof Reed was able to address each student's issues as highlighted by the individual preliminary submissions and the students were then expected to improve on these for the final submissions. The general feedback sessions after both rounds of the oral group presentations covered issues such as design report content, i.e. what each section needed to include, contentious issues that arose out of most of the students' reports, i.e. whether to have a specific unit or not and whether having that unit would adversely affect the economics of the design, favourable physical properties of the different sections of the plant, the type of reactors used and why and finally rules on the different drawings. He also gave some tips on how the students were to make use of values and approaches obtained from literature versus values derived from first principles.

The next section looks at how the students experienced not only the feedback but the Capstone Design Project as a whole.

7.2 Students' Experiences During The Design Project

The table below gives some detail of the students' marks for the preliminary mass and energy balance reports, the section design reports, as well as the final marks for the Capstone Design Project.

Table 8: Design project marks Year 2, second semester

A [28]	Student Name	Preliminary report (M&E)	Final report (M&E)	B [29]	Preliminary report (Individual section)	Final report (Individual section)	C [30]	Final Design Marks
	Brian	75	74	X	75	40		60
	Devon	65	80		50	60		66
	Kathleen	50	59	X	40	40		60
	Katleho	40	58		50	57		55
	Kelly	60	70	X	65	50		69
X	Gontso	60	45		45	58		57
	Mike	65	85	X	75	70		79
X	Nandi	60	55	X	60	40	X	43
	Nazlee	30	71		55	63		61
X	Nolwazi	60	45	X	50	45	X	48
X	Petrus	55	45		45	60		62
	Tanya	55	75	X	70	62		66
X	Tariq	70	45		40	50	X	48
	Taryn	60	67		55	56		59
X	Tasneem	75	70		55	56		60
X	Thabang	75	59	X	65	40		58
	Zunaid	55	75		55	73		65

The table above shows that some of the students improved their marks after the feedback with Prof Reed for each of the two reports while others did not. However the table also indicates that there are those who moved from a passing grade in the preliminary report to a failing grade in the final report for the sections. For the mass and energy balance section these are, Nolwazi, Nandi, Thabang, Brian and Kathleen. Three students did not improve their marks on either report, namely Nolwazi, Nandi and Thabang (see Columns A and B). Two of these, i.e. Nolwazi and Nandi, then went on to fail the design. Thabang managed to pass despite these two poor performances. While some black students do pass, it is noteworthy that, given the issues raised in Chapter 1, all the students who fail the different sections, apart from Brian, are black students. It is worth noting that the preliminary and the final reports were assessed by different academic

28 The X's on this column are those students whose marks did not improve after the feedback with Prof Reed for the mass and energy balance report.

29 The X's on this column are those students whose marks did not improve after the feedback with Prof Reed for the individual unit design report.

30 The X's on this column are those students failed the Capstone Design Project.

staff: Prof Reed assessed all the preliminary reports while other members of staff assessed the final reports. This then suggests differences in evaluative criteria between Prof Reed and the final markers.

Thirty five percent of the final design mark reflected on the last column is a group contribution. After the two oral group feedback presentations each student was individually orally examined by three members of staff. After these individual assessments the three failing students were borderline. They were therefore orally reexamined and it is due to the weaknesses of these second oral examinations that they failed. The students' narratives during the two and a half months of design which give insight into some of these results will be presented on a case by case basis.

In choosing the cases I looked at the previous table and chose those students who failed the Capstone Design Project. In section 7.1.1 I characterized Prof Reed's feedback as strong in terms of the framing over evaluative criteria. Therefore I was interested in finding out 'what went wrong' for these students. I was also interested in establishing whether there were any differences in terms of assessment of options and action between them and those who had eventually passed, even though they struggled. Despite these potential differences, some students managed to produce text that was considered to be legitimate enough to earn them a passing grade. All the student interviews were conducted after the students had completed and been assessed on the Capstone Design Project.

7.3 Feedback And Inferring Realisation Rules

Earlier in the discussion Prof Reed's practice was characterised as strongly framed over evaluative rules; it was his intention to make sure that students were able to infer realisation rules through his interaction with them over their preliminary submissions. This section examines what students decided to do with his feedback. Nolwazi and Tariq failed the design and are discussed first.

Nolwazi had several problems highlighted to her about her submissions during the oral group presentations. However, her final script, according to the marker, had a number of sections missing. In essence she had submitted an incomplete report and when she was interviewed about this during her re-examination, she did not demonstrate that she had managed to think any further about some of the issues that she was not able to address in the report. Below she talks about the feedback from Prof Reed.

> *The thing is, the first time when we did the mass balance, everything was wrong the way we did it. After we met with Prof Reed that's when we understood what we were supposed to do… the only thing that I was concentrating on was to make the target, that was the only thing that I did when I was doing the mass and energy balance. But afterwards when I met with Prof Reed that's when we understood how we were supposed to do the whole thing. (Nolwazi, Interview)*

In this extract Nolwazi is convinced that her first attempt at the mass and energy balance was completely wrong and that it was only after meeting with Prof Reed in the oral group presentations that she was sure what to do. However the disparate marks that she received for the two submissions tell a different story. Her mark for the submission that she describes as 'wrong' was higher than the mark for the submission that she described as 'we understood how we were supposed to do the whole thing'. It seems therefore that from the interaction with Prof Reed she felt she had the realisation rules. However the examiner of her final mass and energy balance submission noted that she had submitted an incomplete report that was mostly qualitative 'with little discussion of interactions between parameters'.

Her section design submission mark reveals the same story. She acknowledges that she submitted an incomplete report for the preliminary section design. Even though she does not speak explicitly about the second feedback session she expresses problems that she had in compiling the preliminary section design. The marker of her section design (the second submission) commented that she had conducted 'a limited study of kinetics with only a few parameters tested'. Prior to this in the second feedback session she had acknowledged to Prof Reed that her kinetics were not working and as such she was unable to complete a number of things. In responding to this issue Prof Reed told her of programmes that she could use to address this and further that her inability to find

'kinetics that work' did not need to translate to omissions of sections. The 'design context' allows for imperfections in the design and allows that some things will not work, which Nolwazi was aware of because Prof Reed told her. Her action in the face of this was to omit these sections that she was not sure how to deal with. However the 'context' does not allow for ignoring those aspects of the design that one is not able to deal with.

Thus it seems that Nolwazi did not have recognition rules. However in the following extract it seems that she understood on some level the role and importance of the design report even in the face of things not working in the design studio.

> *I started writing my report late. So it was too late for me to produce a good report because I was busy concentrating on trying to get my thing to work… So when I was looking at my ASPEN it was optimized. The thing is even if you finish that if you can't write a report of whatever you have done, it's useless.* *(Nolwazi, Interview)*

Her preoccupation with trying to 'get my thing to work', as she puts it, robbed her of the time she needed to generate a good design report. Therefore with respect to the written design report, there is some evidence that she did not have recognition rules, i.e. did not recognize what was appropriate in a written design context. Moreover, because she fails to actually solve her technical problems, as is reflected in the comments of her markers, she has limited realisation rules. Additionally, because she is not able to recognize that for the oral examination one needs to address both what is present as well as what is absent in the design report, which she fails to do, she does not have recognition or realisation rules for the oral examination.

Tariq's preliminary mass and energy balance was described as a good initial effort by the examiners during the feedback session. His mark was 70% for that preliminary submission and all he was told was that he needed to pay attention to the basis for his assumptions. However his final mass and energy submission was failed, and in his interview he revealed that he had omitted most of the energy balance due to an error he had made. He was not able to address that error between the two submissions in the design studio, did not adequately address that situation in the report and for the same reasons as Nolwazi did not have realisation rules. In his interview he mentioned that he hoped in the oral

examination he would be asked about what he had done and instead the examiners wanted him to talk about the energy balance, i.e. that which was visibly absent in the report. He was then not able to answer the questions and all he told them was 'I did not take that into account because of time'.

Nazlee achieved, 30%, the lowest mark for the preliminary mass and energy balance. During the feedback session, Prof Reed was worried about practically every aspect of what she had written.

> *Let me just go through this, all the reactions are wrong, all the streams, it's very concerning. You made an indication about what type of reaction is endothermic and exothermic reaction, but more important is whether it's adiabatic or isothermal.* *(Prof Reed, Interview)*

He was unhappy with what she had done and submitted, and said as much. He then went on to tell her explicitly how to calculate some of the estimates that she had done incorrectly and told her why her method of calculation was wrong. She described her first attempt at the mass and energy balance as a frustrating experience.

> *I had a section in ASPEN, I had a section in Excel then I had another section in ASPEN. I had to link it basically…so every time I changed, I had to bring the results back to Excel, it was such a pain. It was a bit frustrating…I didn't do energy integration in my mass and energy balance at all. I just wrote something on it because there just wasn't time for that. That just totally freaked me out, I just thought 'Okay I'm one of those students that's gone', and I was so surprised that I came through.* *(Nazlee, Interview)*

Nazlee's approach differed from Tariq's in that she understood the limitations of the two computer programmes hence the moving back and forth between the two. However this awareness came after Prof Reed's feedback in her preliminary mass and energy balance report about the two programmes and how the students were expected to use them. She also described how even though she had not done energy integration, she 'just wrote something on it', demonstrating that she perhaps understood that omission was out of the question. Below she described the feedback session as helpful.

> *I mean he (Prof Reed) was very blunt about what he wanted and I think sometimes it's good to be frank and just tell someone even though afterwards you just…he basically just said what he wanted in terms of the feedback. It was very helpful….* *(Nazlee, Interview)*

She described Prof Reed as quite blunt and clear about what he wanted. She was able to then action out his recommendations including the issue with ASPEN. While she acknowledged that she was frustrated due to the amount of work this required, it seems that she was able to infer realisation rules and translated that feedback to a design report.

Kelly and Brian were among the group whose marks worsened after the feedback for the individual unit designs. Brian actually failed his final submission after getting a grade of 75 for his preliminary work. In the feedback sessions Prof Reed asked him about 'plant start-up and shut down' which he struggled to answer. Prof Reed then proceeded to tell him how one would go about doing plant 'start-up and shut down'. However in his report the examiner remarked that he had omitted this part of the report and had failed to 'solve a simple Reactor Design 1 tutorial problem'. Brian had further problems in terms of his computer programme that he couldn't solve that, according to the examiner, resulted in incorrect relations among key variables in the design. Brian was not able to account for these nor for any assumptions made. As such he had no realisation rules for this section but did not fail the Capstone Design Project, unlike Nolwazi and Tariq.

Again there is a question as to whether he had recognition rules. It seems he spent most of the time wrestling with his computer programme but was not able to compile a coherent report which is evidence of incorrectly reading what is required in the design context.

Prof Reed's feedback should arguably have resulted in improvements in moving from the preliminary submission to the final submission. The failure on the part of some students to use his feedback to improve brings to question the differences between the evaluative criteria for the preliminary and the final submissions. There were two main differences between the two submissions. The Capstone Design Project handout states that for the preliminary mass and energy balance, 'computational tools are not required for the initial submissions' (Department of Chemical Engineering: 3). This means that the students

could have managed the submission with the use of MS Excel, and did not need to use more sophisticated computing tools. The same document further states that 'the use of ideal approximations is appropriate here' (Department of Chemical Engineering: 3). This means in approaching the preliminary submission the students did not have to concern themselves with non-ideal (and more complicated) behavior. This second statement supports the first in that in order to deal with non-ideal situations in design, sophisticated computing models are required.

The implication is that the criteria for evaluation were different for the two submissions. The demands of the final submission were higher as the students were then required to shift from a relatively easier, more theoretical approach to one that approximated reality more closely. Nolwazi failed here as a result of spending too much time grappling with the computing side of the design which was not required in preparing for the preliminary report. This left no time for a design report hence the incomplete work. Nazlee however spent a considerable amount of time on computing tools for her preliminary report. She failed the preliminary submission as she had not devoted enough time to the report. However this potentially made her final submission easier to handle in that she had done all the 'struggling' with the computer and could now just concentrate on the report. Hers was one of the better final submissions. The Capstone Design Project course handout also stated that for the section designs students could assume ideal behaviour for the preliminary submissions. This also simplified the computing for the preliminary unit design. However, Brian, who failed his final section design also spent too much time trying to get his computer programme to work but without success.

Regarding dealing with the individual unit designs, Prof Reed directed the students to their prior coursework for all the appropriate procedures, courses such as Reactor Design II and Separation Processes. In designing the individual sections the students used these two courses as points of reference. None of them appear to have used knowledge from the Third Year Design Project in the Capstone Design Project.

The final submissions in both cases, i.e. for the mass and energy balance and for the section designs, were assessed by different academic staff. In making use of the feedback therefore the students had to understand the shift they had to make in terms of the computing; this evaluation criterion was made explicit to the students. They also had to understand that in incorporating the shift, they had less time in which to incorporate the changes and that a complete, fully justified report was more indicative of realisation rules than a computer programme that works but without a design report. Some students understood the latter and others, those who failed, did not.

7.4 Students' Use of Resources

In incorporating the changes to their designs as highlighted by Prof Reed, it is assumed the students would have used resources and it is these that are explored next. In the previous section, Nolwazi's action was to ignore aspects of the design that she was not sure how to deal with. This meant she submitted an incomplete report thus not improving her mark even after the feedback. However, she was aware of this issue before the feedback. After the feedback session she sought help in order to address this issue.

> *I worked by myself but I was also with the people that were doing the unit design so we would discuss, come up with ideas. When we saw that the kinetics were not working we came up with a way. If people's kinetics were giving them something we would ask 'What kinetics are you using?' We kind of worked together.* *(Nolwazi, Interview)*

In this extract Nolwazi admits to having gone to other student colleagues to discuss the section design. It seems that the problems that she was experiencing around the kinetics were experienced by some students as well. The groups of students that she appealed to were people who were not in her allocated design group but were a self-selected peer-affinity group[31]. The self-selected group comprised members who were responsible for the unit design in their groups and were black students that Nolwazi could relate to socially and otherwise. The design group on the other hand was an allocation group and comprised people that she may not have necessarily chosen to collaborate with.

31 This is a group of students who are similar either in terms of race, gender, academic ability, and group themselves along those lines.

Of the latter group she says:

> *My group was not nice because when we started everyone… wanted to do their own thing, I don't know how they do it but they check your mark or whatever…there were two people working by themselves. We would discuss and sit down and everything would be fine. They would assign tasks and then everyone would do their stuff. But those people were the ones putting together the report. So you realised later when putting together the report that the stuff that you did is not even there. And then they also used to like gossip among the group …but they were talking among themselves because they were friends. Otherwise it was not nice…*
>
> *(Nolwazi, interview)*

Nolwazi therefore did not appeal to this group for help, partly because the rest of the members had different section designs of their own to worry about. She appealed instead to a peer-affinity group. She talks of the strategy they came up with which was to use the kinetics of any member as long as they worked. However, as it turned out what failed her was not the outcome of those discussions about which kinetics to use, but rather what she then made of all that work on her own both in the written and in the oral session. She was therefore not able to use the peer affinity group as a resource to achieve performative competence in her section design.

In analyzing this group situation the first point to consider would be whether in such a group, i.e. an allocated group, the relations constitute internal and necessary ones. Considering that the combined resources of the group (cognitive and otherwise) lead to a group report, it might be argued that if any group report is to be of any good, i.e. if it is to be more than different sections done by different individuals and stapled together, the relations among the members must be internal and necessary. This would imply a division of labour with which all group members are happy, which might include the appointment of a person or persons to oversee the final product for internal consistency.

However since this relation is 'peopled', there are invariably socio-cultural issues at work. Nolwazi was operating in a system of ideas in which those students who are not considered academically strong are not seen as valuable members of the group. These ideas were then actualized in the socio-cultural interaction by the more dominant group members who systematically ignored the contributions of the 'less favoured' members. In

the final analysis the group report and the process by which it was produced constituted an emergent property. In Nolwazi's case, this emergent property impinged on her as an agent in as far as it nullified her role within the group thus creating a situational logic for her. She was not happy about this, as reflected in the extract, and turned instead to a peer-affinity group.

On the other hand, the group product contributed only thirty five percent of her final Capstone Design Project mark and as such even if the group had produced a failing grade, her individual work alone could have passed her. Therefore the peer affinity group seems to only have been good for her emotional well-being. Her narrative indicates that she could not discuss things with her allocated design group but was able to do so in the peer-affinity group and as such felt valued. But there ended the utility of that peer-affinity group as she was not able to translate that group effort to individual success. Her reflexive tendencies could not be conclusively described in the previous two chapters particularly because the issue of translating group dialogue to individual success was less pertinent in the previous two contexts. It can now be described as fractured.

Tariq spoke about appealing to senior engineers with whom he had worked as an intern in a company.

> *I phoned certain people… at Chevron, just to get some understanding. I asked them 'Is that right is that wrong?' and they gave me feedback which was helpful. But then again I don't know, I just wasn't catching…* *(Tariq, Interview)*

He admits however that despite this strategy he was still not able to put things together. He also approached his peer-affinity group who managed to convince him to switch strategies.

> *Initially I was going to do what we learnt in Separations to do that, but other students in my class who said but Tariq ASPEN does it for you and so what we decided like two or three so we get together and we model it in ASPEN…* *(Tariq, Interview)*

Again this was a group of students each of who were in other allocated design groups. These were the people he felt comfortable with who were all responsible for the same

unit design in their own design groups, hence the collaboration. He talked positively about his allocated design group experience. The group leader allocated tasks and he felt he had a part to play. In situations where the peer-affinity and allocated design groups were not able to help him his strategy was to then appeal to another type of resource, i.e. 'the good student'.

> *I had to ask my friends but then they also didn't always know and I'd say to myself 'Tariq, maybe ask someone who normally gets good marks. If they're doing it that way maybe you should do it that way'…* *(Tariq, Interview)*

This 'someone who normally gets good marks' then became for him someone whose example should be followed. Out of all these resources however he still was not able to translate this help to individual success. Like Nolwazi therefore he also displays fractured tendencies.

Nazlee was successful in translating the feedback to individual success. Part of the process involved collaboration. Again, the nature of the relations that she appealed to in order to help, were interesting. She described her allocated design group as one which functioned adequately. There were divisions among the group so that certain discussions were happening in little groups within the design group. She also acknowledged that she was unhappy with some of the decisions taken by the dominant members of the group but did not speak out about this. She had two other avenues to pursue however in terms of resources in moving forward.

> *For the unit design, all of the people that were doing the hydrogen cleanup had regular meetings to discuss the types of curves that you want to get, what you're trying to do. We basically collaborated on that regularly, basically every second day, three times a week. We would sit and see what we were doing.* *(Nazlee, Interview)*

She appealed to a peer-affinity group made up of students in other groups that were responsible for the same unit design but that she could relate to socially just as Nolwazi had done. This seemed to have been a formative experience for her. She differs from Nolwazi and Tariq in that she acknowledged that while these group discussions were important in moving forward there were specific aspects that she had to do on her own subsequent to the group discussions.

> *But there were certain sections, like diagrams that everyone did on their own. But in terms of the analysis we basically discussed.* *(Nazlee, Interview)*

In the previous two contexts Nazlee had a preference for working with peers to resolve issues. She carries this through here but manages to achieve individual success and as such is characterized as a communicative reflexive.

Brian also appealed to his peers for assistance. He notes:

> *I was kind of working side by side with two other students who were doing the same thing but then they couldn't really help me because they had their own problems and I wasn't helping them because I was dealing with my own problems. We did and ask Prof Strauss for help and he said he's not teaching and he didn't help.*
>
> *(Brian, Interview)*

He appealed to a peer-affinity group, who were not able to help due to their own responsibilities. Their efforts towards appealing to another member of staff for help were not successful as he did not make himself available. This meant Brian was not able to resolve his technical difficulties for one of the submissions but did for the others, thus displaying communicative tendencies.

7.5 The Internal Deliberations

When Nolwazi found out that she had not passed the individual oral examination and was due for an oral re-examination, she had some thoughts about her prospects in that context.

> *That second one, I just didn't, I don't think I wanted to go. I decided like later on to go and then I feel as if I didn't prepare myself. I think what I should have done was look at other people's reports and then see some stuff and compare … when I went there I was already panicking too much. I just gave up when I got there. I was just like …whatever. I got over it. So by the time they were even asking me something which was very basic I was panicking and wasn't able to answer.*
>
> *(Nolwazi, Interview)*

It seems that after the first oral which had not gone well, she was unsure about whether to even attend the reexamination. It's interesting that in her reflection she thinks she might have done better going to other people and asking for their reports to see where she had gone wrong. Again here she talks about how appealing to other people in this

way may have helped her. She doesn't talk about any other way in which she could have made that second experience more favourable. The stress of having completely misread the requirements on both the submissions appears to have created a situational import for her. She was not in a position to think of strategies that could have helped her redeem herself after that first oral examination. This confirms her fractured tendency where she is torn between different options and ending up not necessarily taking any action partly because, as she says, 'I don't think I wanted to go'. She was caught on the one hand between the somewhat objective reality of the oral in which certain specific things were expected of her and her concerns on the other. After the negative feedback in the first oral, her subjectively defined concerns were under threat which made the process of mediating reflexively between the two a torturous one for her.

Tariq was torn about his choice of resource. In allowing his friends to convince him to switch from one approach to another because '*Tariq, ASPEN does it for you',* it seems this decision was not one lightly taken.

> *But the thing with ASPEN is if you get an output, sometimes you can't really back it up with fundamentals, you just get an output and you don't know where it came from… (Tariq, Interview)*

His concern about using ASPEN was that the programme generated outputs that one could not always defend and this was his reason for not going this route to begin with. It seems however that despite this reservation, he adopted the approach suggested by his peer-affinity group. Further, while he also appealed to the 'good student' this was not a decision with which he was happy.

> *Someone who normally gets good marks and they're doing it that way maybe you should do it that way, but I mean that wasn't on I mean you shouldn't do it that way… (Tariq, Interview)*

He knew that this was not the best way to proceed but somehow still thought he would achieve success that way. His fractured status is therefore reinforced here. He was one who spoke about never being quite sure what to do in the design. The following quote is quite telling in terms of what he thought about the design process. He was responding to my question about whether more time would have helped him produce a better design.

> *I think when it comes to time, you could argue you should get more time or students should know where to draw the line. I think a lot of students including myself were more worried…about getting the answer … I wasn't aware of that going into the design, maybe somebody should have reminded me, I'm not sure maybe I should've have known I'm not sure… but somebody, maybe lectures should just warn students before and say 'Guys do your mass balance. Don't worry about getting the right answer. You can explain everything but write a good report'.*
>
> *(Tariq, Interview)*

Tariq recognised throughout the design that the context was different from what he had experienced thus far in the degree. However he did not appear to individually take control of different aspects of the design and came to realise what was valued only after he had failed. In other words there was no realisation of the text, just partial recognition of the context. In the extract he feels that students should be told or reminded about what is important in design. Students such as Mike however made these types of statements at the start of the design project which meant unlike Tariq, Mike knew going into the design what was important (refer to page 129 for his interview).

Brian, like Tariq, was torn about the decisions he took as a result of his peer-affinity group.

> *I could have used a different programme, which I should have but I just used Scilab™ because the other students were using it. I assumed that I could work with them and get some help. But actually I should have used Polymath™ or MathCAD™. I really started in MathCAD™ but I didn't really get very far at all so I changed, so I should have done MathCAD™*
>
> *(Brian, Interview)*

It seems Brian had different options for the choice of computer programme but ultimately he chose a programme that would make collaboration possible. However he was not able to receive the help he was hoping for and expressed an aversion for 'sitting there for eight hours trying to figure it out'. This was in reference to computer programming.

> *I had to take a programming approach which was to solve differential equations… but I'm not good at programming and I don't like sitting there for eight hours trying to figure it out, so I suppose I could do more, try to get around it.* *(Brian, Interview)*

It seems his aversion for computer programming prevented him from sitting for hours and trying to make the code work. As such he felt he could have done more to get around

the problem. He continuously described himself as lazy and although he passed the design he was not happy with himself throughout the process.

> *I was disappointed with what I got. I expected to get at least ten percent more… I think I was also a bit lazy. I should have really put more into it but since May I really wanted a holiday. I took two weeks off. We were given design before the vacation happened and I took two weeks off for myself because I needed to. But you know it's always at the back of your mind. So I don't know. It was all manageable the work I think. It's just there is not that much balance. Chemical engineering fourth year takes your soul, takes away your soul. It encroaches on that*.
>
> *(Brian, Interview)*

Here he wrestled with his concern for physical well being on the one hand and for achieving performative competence in design on the other. It seems he felt his decision to take the break he felt he needed worked against him, as that time could have been put to better use. Again, while he did not fail, he performed well below his usual academic standard, which was a source of disappointment for him. This decision was not one taken lightly as, even during the vacation, thoughts of the work never left his mind. There is evidence of a communicative reflexive about him in this context. There was evidence of this also in the previous design context, i.e. Process Synthesis and Equipment Design. In third year it wasn't a preference but he ended up going this way due to the range of issues in that context.

7.6 Summary and Conclusion

The chapter presented some detail about the pedagogic practices that set up the interactions that took place during the second semester design project, as well as the students' experience of the design.

The Capstone Design Project context was a demanding context for all students. The convener attempted to explicate evaluative criteria in the oral feedback sessions but these did not translate to success for all students. This was seen to be partly due to different evaluative criteria between the preliminary and the final submissions for the mass and energy balance and section designs, which were not negotiated successfully by all students. The successful students understood that in considering the feedback from Prof Reed they needed to take account of the differences in the requirements between

the two submissions which were spelt out to the students at the start of the design project. In chemical engineering design terms this meant being able to move from ideal systems to non-ideal systems by making use of the appropriate computing tools and combining this with contextual input from Prof Reed.

Moreover the successful students understood the more implicit rules concerning the importance of a complete design report versus preoccupation with the computing. The less successful students tended to exhibit fractured tendencies where the use of resources did not then lead to individual success. This was due to poor decision making regarding which technical routes to pursue, how to deal with advice from friends and in some cases an absence of decisive action and a resigned attitude. It seems therefore that a number of students did not have the personal emergent properties to carry them through a very demanding and a seemingly unfair pedagogic situation.

While the evaluative criteria were made available to students - firstly through course documentation and then through Prof Reed in his feedback sessions - the final reports were evaluated by different academic staff. A number of students did not improve on their initial reports which may suggest that the different academics had different evaluative criteria. This might indicate that the group of academics involved may not have come together to discuss the evaluative criteria prior to assessing the students' submissions. According to verbal communication from one of the staff members involved in marking the submissions, Prof Reed briefed each staff member individually. This is problematic and points to an issue inherent in the Capstone Design Project.

Furthermore, a number of students were concerned about the computing aspect of their designs. This trend was also observed in the third year design context. In that context, the focus of most students' efforts in fixing their errors in the absence of feedback tended to revolve around changing the modeling language. In describing constraining situations a number of students pointed to the computing aspect of the degree as being most

unsatisfactory and as such constraining. Unlike the previous issue therefore this concerns the students' design education in general and the role played by computing in design.

The issues raised in this chapter and in the previous two chapters are taken up more broadly in the discussion in addressing the research question. That section concludes by giving some consideration to issues of structural and cultural elaboration and reproduction.

Chapter 8
Discussion

8.1 Introduction

In Chapter 1 I problematised the high failure rates in the Capstone Design Project, and crucially that it seemed to be predominantly black students who failed. In Chapter 4 I showed that staff in the department of chemical engineering, concerned about the poor performance in the Capstone Design Project, and concerned about improving the design education for all students generally, embarked on a number of reforms in order to change the offerings of some aspects of the design education. Despite these efforts however, the Year 2 cohort of graduating students, seventeen of whom were part of my sample, emerged on the other side of the capstone project with just over ten percent of the class having failed and all of them black students. A similar trend was observed again with the following cohort.

The question then becomes, why is it that despite the efforts and best intentions towards reform, pedagogy still fails? More specifically, why is it largely the black students who fail? The answers to the research questions will attempt to address some of these issues. This chapter will firstly present a summary of the key findings in the three data chapters. This presentation will show to what extent the different curricular reforms succeeded in their intents. This will then be followed by a process of retroductive reasoning to answer the further question of what reality needs to be like in order for things to have been as they were (Bhaskar, 1998).

Concluding remarks will be made pertaining to the potential elaboration or reproduction of structures and the implications this has for the education of chemical engineers in South Africa.

8.2 Summary of Key Findings – The Research Question

The research question that the study sought to address is reproduced below and has been broken down into sections for the purposes of discussion.

How is student success

a) ***conditioned by social and cultural systems***
b) ***shaped by socio-cultural interactions, and***
c) ***mediated by personal emergent properties implicated in the contexts of chemical engineering design?***

Part a) will be addressed in the next section using retroductive reasoning to appeal to the level of the real for generative mechanisms and their influence on success. Parts (b) and (c) are addressed first and represent the social and socio-cultural interaction phase of the morphogenetic sequence.

The outcomes of the study suggest that the capstone design experience cannot be analysed without due consideration of the structures beyond the schools of engineering and the conditioning influences these have on faculty action. While the search for transferrable assessment models, (see Davis et al., 2008), with the capacity to account for variations in the capstone courses in different institutions is laudable, what all institutions have in common is their ineluctable location within a structural and cultural milieu (both in terms of the institution and in terms of broader society) which influences the activities in departments. Current research in engineering (design) education has tended to downplay this macro influence and thus positions faculty as independent agents answerable to no one but their own innovative 'whims' in design education.

This thesis shows that this position is not 'real' and therefore not tenable, and that different kinds of research questions need to be asked in order to generate different kinds of answers in addressing 'performance differences' in engineering education.

8.2.1 Student Success Shaped By Socio-Cultural Interaction

The findings indicate some key ways in which the pedagogic practices failed to live up to the ideals of the lecturers. In third year, which was presented in Chapter 5, the pedagogic practices did not create conditions that were conducive for learning integrated design. In this context the design project convener intended for the students to approach design in an integrated manner, that is, to design a reactor and a separator in one integrated design. To achieve this he strongly controlled the rate of expected acquisition by structuring five consecutive submissions of increasing complexity which culminated in a final report. However he did not return student work for them to implement suggested changes in time for subsequent submission. In this way students were not in a position to identify errors made in previous submissions resulting in the possibility that these errors could be repeated. In situations where there was feedback, the students were not in a position to implement that feedback due to the manner in which it was communicated to them. In most cases the final design report was therefore not an integrated design report. Due to the lack of guidance and feedback, some students tended to obsess over certain aspects of the design project (such as computer programming) and ultimately did not produce legitimate design text, i.e. an integrated design project which took proper account of the necessary engineering science.

Moreover, two other courses that students were enrolled on simultaneously, which provided the engineering science required to engage with the design project, were insufficiently aligned with the design project. This was due to the fact that they presented the necessary design concepts either too early or too late for students to use. This, coupled with poor or no feedback from the third year design project convener, meant students produced design reports that did not advance them much beyond 'thinking in parts' which was not his intention. The entire third year system therefore was characterised by strong framing over pacing in the design project, coupled with weak framing over sequencing and evaluative criteria. This was exacerbated by the strong classification among the two courses and the design project ultimately creating an

invisible pedagogy. The third year pedagogy therefore failed to provide basic design competence necessary to subsequently engage in complex design work.

In the first half of fourth year, which was presented in Chapter 6, the students' design education took a different turn. At this stage, it was assumed that students possessed the necessary basics of engineering science and design, and the fourth year first semester's contribution to the design education was the introduction of heuristics, as well as extraneous considerations such as economic, environmental and physical layout issues. Moreover, the convener of this course, and other lecturers in fourth year, intended for the course to serve the crucial function of preparing the students for the Capstone Design Project.

Unlike the third year situation, students received feedback timeously and with sufficient detail which was communicated to them intelligibly. The most problematic aspect of this course was the time pressure which negated the ideals expressed by fourth year lecturers about students learning about the design system in a non-stressful environment. Additionally, it appeared that this time pressure was due to the fact that the emphasis was placed on unclear evaluative criteria. This meant that those aspects which would make the most significant difference to the students' experience of the Capstone Design Project were not considered the most significant in the first semester. The co-lecturer in the first semester in fourth year was aware of this but the two lecturers did not discuss this issue. However, despite better practices with respect to feedback, the pedagogy in Process Synthesis and Equipment Design was invisible because in the final analysis it did not accomplish what it set out to achieve, i.e. allow students to experience the chemical engineering system they would be dealing with in the second semester in a stress-reduced environment.

In the second semester of fourth year, which was presented in Chapter 7, the students embarked on the design project for which the third year and the first semester of fourth year had been the preparation. The convener of this project had assumed control of the

course from a colleague the previous year, and in an attempt to make this aspect of the students' education more formative, introduced changes. For the first time, therefore, the students were in a position to receive constructive feedback along the way through a range of preliminary submissions and implement these towards the production of a better, i.e. legitimate, design text. The changes introduced were designed to make evaluative criteria explicit to the students.

However, according to the findings, while the convener attempted to make criteria explicit in moving students from preliminary submissions to final submissions, he was not responsible for evaluating the students' final submissions. Instead, this task was left to the rest of the academic staff body who were deployed to evaluate different aspects of each student's work. In their marking, the staff members did not seem to be working with a sufficiently clarified set of evaluative criteria. The students performed poorly in certain aspects of the technical design discourse. These were the energy balance and the analysis of the reactors. There were problems associated with moving from ideal situations to non-ideal behaviour and the use of appropriate computing tools to make this shift. They also tended to produce poorly written design reports. The three students in the sample who failed, failed in all these aspects and their reflexivity did not progress them as it tended to be fractured. This was established only in the final phase of the social interaction.

Ultimately, the analysis of this longitudinal study showed that the lack of a good grounding in the integration of engineering science in a design context (such as was the case in third year) means the fourth year design education does not have a firm foundation on which to build. Furthermore, some students failed to realise what counted the most in the final analysis. They failed to understand that timeous submission of a design report, which gives due attention to the most pertinent aspects of design, regardless of whether the calculations had been completed or not, was crucial for success.

Students singled out computing as one aspect of the undergraduate programme that they considered a constraint. This was evident in the issues that were experienced by students throughout all three interaction phases to do with computing in design. Some students were not able to transcend this issue which thus affected other areas of their design leading to failure. While it was clear what the role of Process Synthesis and Equipment Design in the students' design education was, it was less clear what role the third year project served. Instead, students were pointed to individual courses for procedures to use in the Capstone Design Project.

8.2.2 Student Success Mediated By Emergent Properties (PEPs)

In addressing this aspect of the research question I will again appeal to the analyses presented in the three data chapters. In Chapter 5 students defined their concerns and projects which were to graduate the following year with a chemical engineering degree. This project meant they needed to achieve success in all their course work. The pedagogy in third year and the implications of this for fourth year design were a threat to this project. Chapters 5, 6 and 7 provided answers to the question 'When pedagogy fails to create the necessary conditions for learning, what avenues are available for students to succeed?'

The study showed that in third year, some groups of students exercised corporate agency in an attempt to bring about favourable outcomes for themselves. These tended to be black students. They did not approach the third year design project convener as individuals but rather in groups. Some of them had prior negative experiences at the hands of the convener and felt that it was safer to approach him as a group. However, this did not always achieve the desired result. Students also used each other as resources. This involved organizing themselves into groups. These were peer-affinity groups, where the students had a connection due to similarities in cultural or social backgrounds or their academic abilities. Part of this group consisted of those students who only appealed to groups for help and were not able to work independently. Finally there were students

who did not appeal to groups or lecturers for help, but chose instead to resolve their issues individually.

Much the same was the case in the first half of fourth year. Unlike the third year project, which was an individual project, for Process Synthesis and Equipment Design, students were allocated into groups for the last of the three projects in the course. However, the feedback practices were better than what they had been in third year and students did not feel as 'desperate and lost'. They were under time pressure but mostly managed to navigate this phase of their design education.

However, the situation in the second semester design project was different. This was a 'high stakes', performance environment and some students were quite strategic about managing their tasks and thus their time. For the Capstone Design Project some of the project tasks were group tasks and some were individual tasks. In this context the allocated groups presented yet another situation where students tended to form sub-groups within the allocated groups. These sub-groups were sometimes created along racial lines. For some of these students, this meant a system of intellectual hierarchy, where the 'smart' students were at the top and those not considered smart were relegated to the bottom. Students had information about who was 'smart' and who was not through prior performance in courses. What this meant was that those students who found themselves at the bottom of the intellectual hierarchy were viewed as having nothing to add to the group tasks and were marginalised by their peers. These students then tended to feel undermined and this did not enhance their self-confidence or encourage the development of their PEPs.

It was only the black students who spoke about experiencing this marginalisation. This created situational imports for them leading to anxiety and frustration. Unfortunately, and particularly for the two who then went on to fail the design project, they found it hard to develop the necessary autonomy to progress and produce legitimate text. While I have described group tendencies with respect to accessing resources when pedagogy

fails, there were also related individual differences among the students with respect to the exercise of agency. This was the manner in which they deliberated over their situations towards realising their project of graduating at the end of Year 2. In working with Archer's four modes of reflexivity, she notes that people who seek contextual change, who seek to remove themselves from their natal contexts in order to pursue their projects are *autonomous reflexives*. This was the case for a number of the black students. For them coming to the university represented a shift from their natal contexts, a change from their social backgrounds which implied autonomy. However Archer notes that there is no clear link between social background and mode of reflexivity. The key issue is upward social mobility and defining projects which take you away from your original context on some level. This could also be true of white students.

In using these concepts then I was mostly interested in whether the students continued to exercise that autonomy in negotiating the constraining contexts they encountered in design or whether they relied on their peers using the strategies of communicative reflexives, i.e. communicating first with peers before embarking on decisions and actions. What was most striking was that the three failures in the sample were the three students who were not able to arrive at a point where they were autonomous at any stage during the Capstone Design Project. The rest of the students were able to be communicative and collaborate when necessary but were also able to withdraw and reflect on their own when necessary. Therefore the more successful students were able to exercise different forms of agency (communicative and autonomous) at different times and those who failed tended towards fractured reflexivity.

In employing Archer's modes of reflexivity, three categories of students emerged. There were those who were autonomous through all three contexts, as revealed in Chapters 5 to 7. These students were confident of their abilities and while the unsuccessful pedagogy in third year destabilised all students, they relied on their own cognitive abilities and other personal emergent properties to achieve success. However not all achieved success to the extent they expected of themselves which was a source of disappointment for

them. Furthermore, this category of students comprised all race groups with the majority of them being white. The second category comprised those students who at times were communicative in their reflexivity but were also confident enough to know when to exercise autonomy and progress individually. This group comprised the rest of the white students in the sample as well as some black students. The final group comprised those students who were never able to achieve autonomy in any of the three contexts. They viewed chemical engineering education as something which students can never succeed at on their own (which some students in the second category also professed) and carried this view through to the Capstone Design Project, to their detriment.

The black students in the first category derived their autonomy from their academic achievement. They were among the few black students in the entire class to achieve academic merit from first year, being placed on the Dean's Merit List. Their peers deferred to them in many ways and this was their source of confidence. Due to their academic achievement they were trusted by all categories of students, black and white, and were therefore not among those who were marginalised during the self-selection of groups in the Capstone Design Project. However, of the three black students in this group, one of them was an English second language speaker and despite his technical expertise, his performance during the oral examinations was poor. This meant his design marks both at third year and at fourth year level were poor even though he did not fail.

Finally, my observation of pedagogic practice revealed another trend with respect to avenues available to students when pedagogy failed. This had to do with the physical arrangement of the students in the lecture theatres where the white students tended to sit at the front of the class occupying the first couple of rows and occasionally stopping the lecturer and 'chipping in' during the lecture, while the black students mostly occupied the middle rows or the back rows, and did not engage in the same manner with the lecturer.

The classification of physical spaces in the lecture theatre points to the different ways in which the student–lecturer pedagogic relation is experienced by different students, which is then carried through to 'one-on-one' student-lecturer interactions. This phenomenon could be explained by the differences in the forms of control in contexts of communication that different types of students experience prior to entering university, which then either get reinforced when they arrive at the academy (such as appears to be the case for white students) or turned upside down for other students (in this case black students).

The start of this section referred to agents' personal emergent properties and thus far the groups of people considered are the students and their responses to the pedagogy. Other people implicated in this are the lecturers and as such their emergent properties in as far as they mediated student success need to be mentioned. In applying commonsensical thinking to the problems created by the pedagogic practices, one would be tempted to suggest that the main problem was lack of communication. For the third year design project to be a true collaborative effort the three lecturers whose courses were implicated could have met together before the start of the project in order to set up the project, the outcomes, the periodic assessments and the project weighting. Over and above this the team could have met during the semester to discuss problems, with the help of tutors deployed to assist during the studio sessions. Instead none of this communication took place.

The same applies to the fourth year course Process Synthesis and Equipment Design. The two lecturers involved could theoretically have met and settled the issue of the assessment outcomes and the 'appropriate workload' which would not work against the learning outcomes. Ultimately the students did not get the benefit promised by the Process Synthesis and Equipment Design course which were to be introduced to the process they would be designing in the Capstone Design Project in the second semester. Finally, in the capstone project, the convener could have convened a meeting and made

clear to all academics what the evaluative criteria were to create an equitable situation for all students, but this did not happen.

In all three contexts therefore, the lecturers could have exercised agency differently with potentially different implications for student success. Instead what occurred was that the same trends in terms of student success as were observed in previous years with previous cohorts of students were reproduced at the end of this social interaction phase.

A significant point to note at this stage has to do with the experiences of the students in the programme. This programme is a highly intense, performance-based environment, as is evidenced by students' array of concerns in Chapter 5 which all have to do with performative competence. The practical order is dominant, but students acknowledged that the social and natural orders often paid the price for this which further impacted negatively on the practical order. Therefore it is clear that the environment in general is one in which students are constantly negotiating constraints, assessing options and crafting courses of action. Inferior programme offerings, i.e. with regard to computing, further create situational imports for students, thus limiting their range of available resources.

However, the study points to the fact that black students have to contend with further constraining issues over and above other students in the programme. This has to do with other students' ideas about what black students can do, as well as students' own views about accessibility to lecturers due to prior negative experiences. This was most evident during the student–student relations where some of the students were sidelined in the group's allocation of tasks. It seems that when the white students are assessing the range of options available to them as part of navigating situational imports, they are in the more powerful position of deciding who in the group will contribute to the group's success. Unfortunately it seemed that in most cases black students were disempowered by this.

This phenomenon was raised by some of them in Chapter 5 as a general constraint that they have to live with. In other words, even in earlier years, in smaller group projects or practicals, they experienced the same marginalisation. It seems also that some lecturers unwittingly make the situation worse by constantly referring to the inferior education that some of the black students have received. These are all issues which impact on the students' emotional well-being and this impacts on their reflexivity as well.

In Chapter 1 I defined my objectives and purposes as both to describe and to explain. The previous section provided descriptions of events and contexts and in the next section my aim is to provide an explanation for what was observed. In doing this I will ask the transcendental question: 'What must the world be like for these events and experiences to have occurred?' This requires a shift to retroductive reasoning.

8.3 Causal Mechanisms and Student Success

To begin this section the question of interest to me is: 'Why was the commonsensical scenario presented at the end of the previous section not actualised?' Why would it have been considered 'burdensome' (as declared by one of the three lecturers in third year) to have been involved in the project, given that such involvement would have improved the students' experience of the design project, not only in third year, but potentially in fourth year as well? The next question is about the level of accountability that exists under circumstances such as these. In other words, would there be repercussions if pedagogy failed to meet up to its ideals (as it did in this case)? What rewards are there for those who do contribute to the university's educational mission? What are the repercussions to those who do not, or indeed, what do individual academics get rewarded for in the academy? How do they allocate their time, what is beneficial to them in the final analysis and will allow them to realise their own concerns?

8.3.1 Quality Assurance versus Reward and Recognition

In view of the idea of the stratified nature of reality as presented in Chapter 2, these questions shift from the level of the empirical and the actual, to the level of the real. At

this level the questions are about the potential causal mechanisms with their generative powers to condition events and experiences. I will look at the quality assurance management system (of teaching and learning in particular) as a potential causal mechanism which fails to have its intended effect because other mechanisms such as the performance management and reward system are in a contradictory relation with it.

According to Hall, Cornielse, Moore & Shay (2001)[32], quality assurance of undergraduate teaching rests on staff recruitment and selection as well as on performance planning and review (PPR). They acknowledge however that both of these systems are flawed. In particular they note that the PPR system lacks an upward reporting mechanism such that 'our teaching practices (both good and bad) tend to be invisible for the purposes of our own reflective conversations within the institution' (2001: 20). This means that while academic staff members are obliged to meet with their heads of department at least once every three years (for senior staff members) to plan their activities, and once every year to review staff members' portfolios against criteria for the job, the outcomes of these meetings do not get reported systematically beyond the departments except for promotion considerations. Hall et al. argue that the importance of performance reviews should be appreciated in their own right and not only when it comes to promotion considerations.

In addition, the information from the performance review meetings, Hall et al. (2001) argue that guidelines that set benchmarks for acceptable practice should be available. For the EBE faculty these are available in the form of a teaching and learning charter which stipulates that by accepting employment onto the academic staff of the University, lecturers undertake to

> *Provide all reasonable assistance to students to enable them to succeed in their studies. This requires that they deliver lectures and other scheduled classes and make every reasonable effort to make alternative arrangements if they are unable to do so. Teachers should be available for*

[32]This report is based on a review of aspects of quality assurance at UCT by the Quality Assurance Working Group (QAWG) and was prompted by the statutory requirements for quality assurance in higher education institutions that have come into force with the launch of the Council on Higher Education's Higher Education Quality Committee (HEQC).

> *student consultations at reasonable and clearly-advertised times, and should hand back student work timeously, and with appropriate comment (Faculty of Engineering and the Built Environment, 2006: 2 - 3).*

The instance of 'bad practice' revealed by the data suggests that these 'deliverables' outlined in the faculty document were not met. Hall et al.'s report suggests that this information will remain invisible, not only at institutional level as they suggest, but at departmental level as well. The implications are that an opportunity for promoting reflective conversations about teaching practice has been lost, potentially condemning practitioners to repeat the same mistakes, due to lack of accountability.

Hall et al. (2001) point out that any system of quality assurance that is developmental[33], such as this one is, needs to have rewards and incentives. This takes us back to the set of questions raised earlier. This faculty's system of rewards and incentives is based on a combination of self-review and peer review which according to Hall et al. provides objective criteria against which candidates are ranked and scored for the purposes of promotion. *Ad hominem* promotions therefore are one of the primary ways in which staff members are rewarded for their contributions to the academy. However teaching and learning is not the only area of competence on which a promotion is based. The implication is that other areas also matter and the question then becomes: 'What is the importance of teaching compared to the other areas?'

On this note Hall et al. argue that for research intensive universities such as this one (as declared in the university's mission statement), the peer review systems tend to be 'steeped in strong concepts of an established order, and tend to be inherently conservative' (2001: 22). They further note that,

> *A manifestation of this tendency has been reluctance on the part of research universities such as UCT to recognize the value of teaching unless good teaching is matched or exceeded by a strong research record. It is a lore in academic corridors that junior staff who concentrate on innovative teaching and neglect traditional measures of research will jeopardize their careers (2001: 22)*

33 Developmental according to Hall et al. means it has at its centre the enhancement of academic staff by finding ways to reaffirm the primary task of lecturers by promoting and supporting good practice through opportunities for professional development and by strengthening the ways in which sound and innovative teaching practices are acknowledged.

According to the teaching and learning report of 2010 at UCT, there is a persistent perception that teaching continues to lag behind research as an activity that should be rewarded. The same report states that projects aimed at improving teaching do not reach all staff. Nothing further was said on the latter point and therefore it is not clear as to the exact nature of the issues associated with this failure to reach all academics.

The phenomenon of academic excellence being equated largely with research was raised in Chapter 4. It is however not unique to UCT. In a study conducted by the Higher Education Academy in the United Kingdom, with a view to understanding the factors associated with the reward and recognition of teaching, Ramsden (2009) concludes that most academics[34] feel that the status of teaching is low compared to that of research and that the function of teaching in higher education and overseas has become unrecognised and unrewarded as compared to research. He notes that 'research tends to dominate teaching in international league tables and to be perceived as a principle source of individual academic status' (Ramsden, 2009: 2). This view is supported by other studies done in Australia (Ramsden, 1995) and the United States (Fairweather, 1996). These report a trend where higher education institutions do not recognise and reward teaching as consistently or as often as they do research. The general consensus among all these studies is that in order to raise the status of teaching, reward schemes, e.g. for promotion, need to be revised.

According to Ramsden (2009), in Australia there is a discrepancy between policy statements about the value placed by institutions on teaching and the actual experiences of the academics. At UCT, the responsible department and faculty have both declared a commitment to improving teaching and learning. However certain practices, such as the poor reporting systems and structures mentioned earlier, cast doubt on the validity of these espoused statements. The EBE faculty website has a link to awards and achievements for the faculty, naming a few recipients of such awards each year. The website shows a number of awards for the years 2006 and 2007. Notably in 2007 three

34 This refers to the academics that were part of the study.

awards are listed: the Distinguished Woman Scientist Award, the Young Scientist Best Presentation Award and the National Science and Technology Forum Award. This list omitted the recipients of the Distinguished Teacher Awards for 2007. The university awards four of these per year and for 2007 two of the four recipients were from the EBE faculty in two different departments. While these awards are not international, they are indicators of excellence. Their omission, in a faculty that claims to endorse teaching and learning, arguably undermines this commitment.

The question of the nature of rewards necessary to encourage excellence in teaching so that its status is raised was also problematised in the reports mentioned earlier. Some of the principles mentioned for successful schemes towards this end include the professionalisation of teaching at universities, clear definitions of what good teaching entails as well as demonstrated support for staff who are committed to this route. Ultimately however the research indicates that rewards in the sense of promotions to higher ranks (and not for example once-off monetary amounts such as those awarded to the Distinguished Teacher's Award recipients) would prove to be the most successful because 'that is what academics understand' (Ramsden, 2009: 6).

While there may be value in following the promotion route as a way to reward teaching and to therefore raise its status, promotion applications are not annual events. It takes a number of years for a person to move from junior lecturer to senior lecturer and to move from senior lecturer to associate professor and so on. Without proper upward reporting systems after performance reviews and proper accountability at departmental level, 'bad teaching practice' has the potential to be repeated year after year without being dealt with. This amounts to several cohorts of students having less than optimum educational experiences. Moreover, performance review forms, which are completed bi-annually after each review meeting, do not capture detail of the actual day to day practices in lecture theatres. Part of that information is captured in course evaluations completed by students.

According to Hall et al. (2001), course evaluations are a qualitative mechanism to indicate the quality of a course. They make two points about student course evaluations. Firstly they argue that course evaluations tend to 'focus on in-class performance of lecturers and the evaluation of tutorials, assignments and reading materials is often not included in the evaluation' (2001: 14). Secondly they point out that course evaluations are the property of the course convener and the head of department, and as such may not always be passed on to programme conveners for the consideration of programme committees.

I want to suggest that, in the data presented, it is precisely the in-class[35] 'performance' of the lecturer that was under investigation. Bernstein's concepts of classification and framing were used to give an indication of both the lecturer's performance in class as well as the other components that Hall et al. mention above. The chapter showed that it is precisely those in-class practices, the nature of the student–lecturer pedagogic relation during the social and socio-cultural interaction phase that have the potential to specialise consciousness in students. Until this 'information' is captured and reporting mechanisms are employed (to further conversions about improving practice in the higher echelons of the institution as mentioned earlier), it might not be possible to understand why certain categories of students fail as reported in the Capstone Design Project and mirrored in the institution's Teaching and Learning report and national studies (see Scott, Yeld & Hendry, 2007).

The second issue Hall et al. raise is that course evaluations do not get passed on to programme conveners to be considered by programme committees. This could be a symptom of the type of quality assurance system that UCT has adopted. According to a report by the Quality Assurance Working Group (herein QAWG), UCT has chosen to adopt a model of quality assurance that encourages self-evaluation and development and locates as much responsibility for quality assurance as possible in the hands of the

35 By this I mean in class as well as the lecturer's performances regarding student work. This is quite separate from issues to do with textbooks and tutorials. I was interested in the practice as it pertained to students' own productions.

academics. According to the QAWG (2004) the focus of the self-evaluation model is on the institution's own capacity to identify problems and to then address them effectively.

According to Luckett (2006) this approach is based on a model of QA sympathetic to collegial rationality which means that it is conducted within the norms and values of 'communities of scholars'. She notes that the purpose of this approach to quality assurance is aimed towards the enlightenment of academics in departments, for them to 'learn more about their practices and as professionals, determine how to improve, so that students learn better' (2006: 37 - 38). She further notes that while the institution may be involved to support the evaluation and to make sure that improvements do happen, it is the academics who are the key agents of the process. Staff in this model are at liberty to involve their 'peers' in the sense of outside academics who are in the same discipline and as such share a 'feel for the game'. This model tends to view students as novices and while course evaluations may be considered, they do not have stand-alone weighting. According to Luckett

> *The findings of the evaluations…are usually reported in a diagnostic and advisory manner, that is, the prodUCT of the evaluation is ideally useful inside knowledge that can be used for formative purposes. The findings of the evaluation are owned by the staff concerned and it is up to them to exercise their connoisseurial or professional judgement and decide how to take the findings forward and what measure of improvement are required. They also determine to what extent the findings should be publicised. Because the purpose of the evaluation is intrinsically motivated enlightenment and improvement, the outcomes or consequences of the evaluation are typically non-threatening and are unlikely to be linked to any extrinsic rewards or punishments. (Luckett, 2006: 38 - 39)*

Luckett notes however that this model can be incestuous and protectionist due to the intimacy involved. She notes that cover-ups and avoidances are permitted thus allowing power and personality issues to get in the way of sound judgment. Finally she notes that this model assumes that all academics are motivated by professional pride and that they do care about students, and the status of their department and institution.

I would argue that this model and method of quality assuring teaching and learning, while invoking feelings of warmth at the notion of 'community of scholars', may in fact be working against the purposes for which it was developed. Indeed the foregoing discussion

presents a range of contradictions at the level of causal mechanisms, the consequences of which are then left to the individual academics to negotiate. I want to discuss two such contradictions which are different but are related to each other. The first is the institution's espoused commitment to transformation, with teaching and learning used as one of the vehicles towards that end, plus the university's commitment to excellence, in so far as it pertains to research. I want to argue that these two imperatives represent a situational logic of constraining contradictions. The second contradiction is that on the one hand the institution is committed to the idea of quality assurance as 'the measure of value of what we do' but on the other hand it then subscribes to a quality assurance model underpinned by a commitment to a liberal notion of 'academic freedom' thus making accountability difficult to attain. The first contradiction has implications for the second. I will discuss both, as well as the situational logics that are then created for academics that inhabit this space. I want then to argue further that their actions, viewed as outcomes of their deliberations about the situational logics, condition student action in particular ways in the realm of social interaction.

8.3.2 Specifying the Situational Logics for Lecturers

Earlier in the discussion I argued that academics in a research university such as UCT operate in an environment which requires them to deliver quality in teaching, but conveys a contradictory message which emphasises the importance of research output for individual academics. The QAWG report (2001) notes that academic staff in universities do not have to have teaching qualifications and many do not. They argue that the re-qualification of academics in order to combat this scenario would be counterproductive as in many cases young academics are under pressure to launch successful research careers. The implication here is that there would be no time for the re-qualification of university academics because there are more pertinent 'things' to do, i.e. developing a research career. This emphasis on launching a successful research career is further strengthened by the funding that is made available for young researchers to 'kick-start' their research careers. No such funding is available to allow academics to

become familiar with the 'other' of the two primary functions of academics, i.e. teaching, and management and leadership.

What is perhaps paradoxical is that some of these academics do not necessarily view teaching in a bad light. The academics in this study for example had genuine concerns for student learning and it was these concerns that were the impetus for some of the course level changes. In a study by Nature Education (2010), it was found that university scientists felt that teaching was as important as research but because they felt that their universities valued teaching less than research, their actions in the teaching context did not reflect their perceptions about the importance of teaching. Inherent in this then is a particular situational logic which results in certain courses of action and decision-making by members of staff who find themselves in such contradictory situations. I want to define this contradiction as constraining because university reward and recognition structures, as well as quality assurance structures (as discussed above), become constraining causal mechanisms in terms of what lecturers could achieve in teaching. This does not mean this situation is deterministic, but only that lecturers are then conditioned in a certain way by these mechanisms. This situation activates constraints because lecturers have defined projects to realise their own concerns about their academic careers.

I have chosen to call these contradictions constraining rather than competitive even though the perception in research-led institutions is that there is a competition between the imperatives of research and teaching. Research-led is in fact not the right term for the argument I am intending to make. In the university's mission statement 'research-led' is defined as a commitment to allow research to lead the university's activities including teaching and learning. According to Jenkins & Healey (2005), research-led means that the curriculum is structured around subject content, and the content selected is directly based on the specialist research interests of the teaching staff. They argue however that teaching tends to be based on the traditional 'transmission' model and that emphasis is more on research findings rather than research processes.

The term I want to use is *research-intensive*, by which I mean that research is valued as a symbol of excellence. Even though in some parts of the world, such as the United Kingdom, some institutions define themselves as exclusively teaching institutions, UCT is not one of these. It defines itself as research-led but defines the core functions of an academic as teaching and research (Hall et al., 2001). This implies that being an academic in this institution means living with both of these imperatives even if in reality the academics are only committed to one. A *competitive contradiction* in Archer's terms would be a case where invoking one does not invoke the other. This is not the case at UCT; being an academic here means one has to engage with both teaching and research, regardless of one's perceptions about the importance of the one relative to the other.

Archer argues that *constraining contradictions* create a situational logic of correction in which case agents choose to correct A to bring it in line with B, correct B to bring it in line with A, or correct both so that they are mutually consistent. I would argue that academics in this institution would not be in a position to correct both, thus making them mutually consistent. There are neither the resources nor the time for that route in that if they do not have teaching qualifications it is difficult to engage in teaching informed by *educational* research. Moreover, and perhaps controversially, if there are no real consequences for practices that are 'less than professional', either due to poor reporting mechanisms or the type of quality assurance models at work, what would be the point?

In correcting this situation the preferred mode of action, which I would argue is supported by the approach to the quality assurance of teaching and learning adopted, is one which tolerates one condition while fully committing to the other more rewarding position. The implication would be to do that which is the minimum with reference to the less favoured position, hence potentially compromising or containing it, and spend more resources (time and mental resources) on the favoured position. By bare minimum I am referring to those strategies that would be considered 'less burdensome', to use the words used by one of the lecturers in the study. The common refrain would be something such as 'I am not involved', such as was used by another lecturer in the study. Yet another

academic used the words, 'I just let him do what he likes' even though he was aware that it was not in the best interest on the students at the time. The implication is that these academics see themselves as carrying a heavy load and 'do not need to have extraneous responsibilities put on them' which they could do without.

This attitude is unfortunately exacerbated by the notion of *independence* inherent in academic freedom as it is defined by the Education White Paper (referred to in Chapter 4) which encourages the notion of 'the absence of outside interference'. In this definition, the 'impermeable' boundaries, i.e. strong classification, are between the institution and the government, or external quality assurance agencies. But I am arguing that the same impermeable boundaries exist between academics which allow them to 'not interfere in each others' areas of expertise', i.e. courses they convene. Because, as alluded to already, since collegial rationality allows individual academics to be the key agents of the evaluation of their courses they may 'tacitly protect each other from failure (by remaining aloof), for their turn will be next' (Luckett, 2006: 39, emphasis in paranthesis added). This situation is highly at odds with the espoused purpose of collegial rationality as an approach to quality assurance. The harsh research agendas imply that, contrary to the espoused purposes of collegial rationality, academics may not in fact learn more about their teaching practices because the system does not deliver on this. Furthermore, there is no one in a position of power, e.g. no HoD, with sufficient educational expertise or discursive resources to comment on the quality of teaching. As such, teachers may not improve, and students may not in fact be provided with better learning opportunities.

Another paradox in this situation is that the academics in this study are part of a department that has a good reputation for issues related to academic development and education research in general (refer to Chapter 4 section 4.3). But it seems that this expertise is differentially distributed within the programme.

To conclude this section, the argument being made is that it is difficult to assure the quality of teaching and learning when the key agents do not 'interfere' in each other's

areas because the system is underpinned by a notion that validates a 'no-interference' approach (couched in the discourse of respect for each other's autonomy and expertise), and the institution's enduring legacy sends a message which says teaching and learning is not in fact (or not yet?) 'our core business' even though we are committed to it in principle. Luckett (2006) notes that collegial rationality as a quality assurance approach produces findings that are linked to the interests and concerns of particular teachers and contexts. She notes further that judgements about effectiveness are based on collegial agreement that improvement has occurred. She cites Barnett who endorses collegial rationality:

> *A genuine interest in the education process involves intricacy, particularity and intimacy and, of course an understanding of context. This means that a concern about educational process is usually incompatible with the instrumental reason that works through quality as ideology, an impatient ideology that wants judgments and therefore cannot give time to do justice to detailed evidence. (Barnett 2003: 96 cited in Luckett, 2006)*

The notions of 'context' and 'detailed evidence' that Barnett refers to demand further exploration. In Chapters 5 to 7 I provided the detailed evidence of the context where close-up socio-cultural and pedagogic interactions occur. It is precisely because contexts are misunderstood that systems fall apart. A different kind of evidence is required than what is currently available if quality assurance is to further the institution's commitment to teaching and learning and to transformation.

A further contradiction exists between the intrinsic nature of engineering design knowledge and the associated pedagogy to transmit that discourse. The two I would argue are related. Engineering design was described in Chapter 4 as the culmination of the degree where all skills and concepts learnt in the degree come together in the design project. Arguably then any attempt to teach integrated design requires the lecturer to understand that they are in fact relaying a form of knowledge and a form of knowing. They are teaching students the nature of the knowledge but also how to go about gaining that knowledge and how to be a design engineer (the practice of the profession). The lecturers' practices however failed to pay attention to the 'how' of design pedagogy.

Their ability to convey the design discourse, the knowledge, was constrained by their approach to the pedagogy. The implications of this for the students are discussed below.

8.3.3 Causal Mechanisms beyond the Institution

In Chapters 5 to 7 it was shown that the interactions in the socio-cultural context shaped some of the actions and decisions that students made in the context of design. This was both from the perspective of student–lecturer relations (both in class as well one-on-one relations) as well as student-student relations (both allocated groups as well as peer groups). This range of different actions meant students enacted agency in a variety of different ways with certain categories of students choosing certain actions, with varying levels of success. The findings indicated that pedagogic structures conditioned student action by providing a limited range of options from which students could choose in order to craft courses of action to realise their project of passing design. Educationally the particular pedagogy observed in third year (Chapter 5) meant that the design basics were not necessarily well cemented. Therefore the fourth year design pedagogy in the first semester of fourth year (Chapter 6) invariably built on a weak design foundation. This, coupled with an invisible pedagogy, meant students had to further draw on their own resources in order to succeed in the Capstone Design Project.

For some categories of students the failed design pedagogy did not necessarily mean failure in design or a weak design foundation. For this group, despite the implicit code and the invisible pedagogy, they realised appropriate text. The argument is that this success was not only attributable to individual student cognitive capacities, but rather to the range of different ways in which different resources were available to them and how these were accessed and subsequently used to help them towards realising their projects.

This section considers social and cultural systems beyond the university as potential mechanisms behind the ‘notion of difference’ in the approaches adopted by black students leading to differential success rates. In order to do this however the notion of success had to extend beyond passing to include performance at one’s best. This means,

in offering an explanation for the 'differences', I recognize firstly that not all black students fail, but that even those who do pass have a different educational experience to their white counterparts. Retroduction allows for this difference to be interrogated by allowing me to ask 'what must reality be like for some categories of students to fail?'

In looking at this issue I want to appeal to what the QAWG termed the 'less tangible aspects of institutional culture'. These are issues to do with dimensions of difference such as race, gender, sexual orientation or religion, and which impact in complex ways on students' learning experiences. The QAWG argues that any quality assurance system must take account of these issues. Steyn & van Zyl (2001), in a study of students' perceptions of the institutional culture in UCT, noted that 'while they may not always be able to articulate what it is they experience, many black students have a general sense that the system does not work for them … the discrepancy between the worlds which the white and the black students inhabit as they move through the university system was quite apparent' (Steyn & van Zyl, 2001: abstract). Some of this can be seen in the level of framing in the regulative discourse in terms of personal and positional modes of control. Personal modes of control, where the student is viewed by the lecturer as 'an equal' validates the student's educational efforts, creates confidence, allows them to trust their own instincts and judgments and helps in developing autonomous tendencies. In this way personal identities are shaped thus enhancing students' personal properties. In this study, and arguably in other racially differentiated educational contexts, this same avenue of development is not easily available to black students.

The educational implications of this extra access that white students appeared to enjoy (due to the personal versus the positional modes of control), are that the implicit aspects of producing legitimate text are lost to black students. In many ways this was evident in the third year and in the fourth year first semester contexts. The Capstone Design Project context formalized equal informal access to the lecturer. Access to those aspects of legitimate text that made the difference between failure and success were not always available to other categories of students. On this, Gamble & Hoadley (2011) note that

personal modes of control depend upon previous socialization to it. In other words it is the students' backgrounds prior to entering higher education which then also seem to determine what happens in these pedagogic contexts in the academy.

Chapter 4 provided detail of how the apartheid regime distributed knowledge to different race groups by providing differential access to education which resulted in poor school output and which, according to Asmal & James (2002) also meant mathematics and science education were specifically neglected. This, coupled with unequal distributions of economic and symbolic power, meant students were differentiated along socio-economic lines (Scott et al., 2007). Scott et al. further note that socio-economic differences affect people's chances of becoming candidates for higher education, of gaining access to programmes and of completing a qualification. They further note that socio-economic inequalities result in differences in educational backgrounds which are manifested in wide differentials in preparedness for higher education.

Moreover this differentiation meant students were born into highly differentiated natal contexts with the potential to affect their capacity to develop the personal identities required in the programme and indeed in the institution. By appealing to Bernstein's pedagogic device, it can be said that this differential access to knowledge served to specialise individual consciousness in specific ways, which according to Muller & Hoadley (2010) is observed in the evaluative rules of the pedagogic device.

> *At this level (of the classroom and through acquisition) it is possible to see what the work of the device has been, in other words in terms of distributing what knowledge to which social groups…it is at the moment of evaluation that we see the extent to which the distributive rules (both in terms of instructional knowledge and social norms) have been realized (2010: 174)*

In these moments of evaluation, particularly in the Capstone Design Project, the findings indicated that the white students had access to a specific spoken discourse with respect to design which rendered 'technical speak' accessible to them. They did not develop this during the capstone course but through the degree, partly due to the personal mode of control and the 'extra' access to academic staff resources that this provided.

These oral examinations were positioned as conversations between a client (the lecturer) and an engineer (the students), so that the white students occupied those roles less problematically than other categories of students. There is, of course, the issue of English language proficiency here. However I would argue that this is an inevitable outcome of a culture in which modes of control are differentially distributed among different categories of students. Of most concern is that these 'conversations' were not formative; students were being judged on these performances. In many ways then, the roots of the differentiation in success are obvious. Moreover this situation is exacerbated by the fact that students in this programme do not 'get coached' in 'technical speak'; they encounter it for the first time when they are being evaluated in the Capstone Design Project.

The white students were better able to grasp the recognition and realisation rules of the pedagogic code. They were able to realise a code that for all intents and purposes was implicit. According to Wheelahan (2005) this means that students implicitly understand the assessment process and how to produce the 'right' outcome. This, however, according to Bernstein (2000), is the function of the distributive rule which regulates the relationship between knowers and knowledge and which regulates access to disciplinary knowledge through class background. Wheelahan states

> *Students who come from families rich in cultural capital who are comfortable using abstract reasoning and other culturally acquired capacities for success in education are much more likely to have access to disciplinary knowledge at school and beyond ... In this way, the distributive rules distribute access to different kinds of knowledge, different ways in which knowledge can be used (to think the unthinkable), and different forms of consciousness (2005: 5).*

The issue of the difference in accessing resources raises another important point. Choosing to approach lecturers for help in groups, if at all, was a deliberate course of action for black students in correcting a situation rife with contradictions in socio-cultural interaction. Being side-lined in some group activities because they were viewed as not strong enough academically to contribute, or being the recipient of a misplaced comment from a member of the academic staff about their academic abilities meant students were operating in a contradictory cultural space. On the one hand they were admitted to the

programme and as such 'had potential', but on the other they lived a reality which seemed to convey to them that they actually did not have the potential.

Immediately upon entering higher education they observed a classification of spaces which conveyed to them a norm about who has access to what and when in the context of a lecture. Further, while for some of them adapting to a university context marked a considerable change from schooling, for white students it seemed that the transition from school was seamless. All this robbed some of them of the necessary confidence to put forward ideas and courses of action toward realising text. Their *Internal Conversation*s did not take them far enough for meaningful courses of action to be crafted and as such were not able to mediate constraining structural and cultural conditions.

In the final analysis, therefore, those who failed the Capstone Design Project did not fail only because they had not mastered the technical aspects of chemical engineering design. Rather, a range of other personal emergent properties needed to be available, (such as reflexivity) a requirement arguably peculiar to the design context. Even cognitively strong individuals can fail to realise their full potential if structural and cultural emergent properties create unfavourable situational logics for learning. This was most evident for black students. A number of those in the sample were as strong as their white counterparts at the start of first year. However by the end of the four years (for the few who managed to finish in minimum time), the difference in grades was considerable. The latter part of the chemical engineering programme is quite design-orientated which requires students to draw more strongly on more than their cognitive powers. This 'more', as already explained, was and is available to white middle class students but not as easily available for other categories of students.

In fact these students were failed by the system as it did not provide them with the best chances for success. However some of the black students also failed to manage a stressful situation in design contexts by failing to appeal beyond what their primary agency offered

to realise their project. They did not have the appropriate social roles with respect to personifying a successful engineering design student. They had very little confidence and received very little validation either from their classmates or from their lecturers prior to and during the stressful design environment.

Scott et al. note that

> *Diversity in the student intake, particularly in respect of inequalities in educational background, challenges the validity of traditional, unitary educational processes. The current student performance patterns support the contention that, where there is substantial diversity, a unitary process cannot realise the potential of the full spectrum of the intake, and inevitably favours certain student groupings over others. Traditional educational structures and approaches will favour the 'traditional' student groupings around which they evolved (Scott et al., 2007: 41).*

Arguably however if the institution is committed to transformation, this means it is precisely this tendency that it would need to address. Scott et al. (2007) argue that as much as there are some factors that are beyond the higher education sector to control when it comes to improving teaching and learning, issues such as institutional culture are among those factors that are within the higher education sector's control to change in order to improve teaching and learning.

8.4 Conclusion and Comments on Morphogenesis/Stasis

One of the questions that the morphogenetic sequence asks is whether in fact there has been morphogenesis (structural and cultural elaboration), or whether there has been reproduction or morphostasis. To observe these changes requires time. In this study the issue is: 'Did the results of the social interaction act on the structure to change it?' To address this question requires a distinction of levels. For example, at the level of pedagogic structure, there was a change to how the third year project was run in the year following the year of the study. However, the change wasn't prompted by corporate agency on the part of students or even their exercise of primary agency. What prompted the change instead was a contingency – the fact that Prof Strauss was on sabbatical and therefore was not physically present to re-run the design project. The lecturer appointed to run the course that year had a different set of ideas on how to proceed and thus the

course format changed again. It was structured differently and administered differently and did not have the same emphasis on 'integration'. Anecdotal evidence suggests that the project appears to have created similar situational imports again for this group as it had for the sample in the present study.

With respect to cultural elaboration or reproduction in the department, what the study indicates is that the response of the black students to the situational logic in which they found themselves led to a situation of correction. They corrected their actions to fit in with the status quo. They could have approached the lecturers in the department and tried to shift their tendency to refer to their disadvantaged background. They could have confronted their white colleagues during group allocation tasks, and voiced their displeasure at being sidelined. Instead, they chose to remove themselves from potential conflict by grouping with their own and 'getting on with things' so to speak, by not going to lecturers to ask for help and, for some, by working in groups. In this way, the discriminating power relations will continue to be reproduced so that future students are likely to have the same experiences.

In reading through the data chapters one might argue that it was inevitable that the third year integrated system failed as it was in its first year and the issues raised could be 'put down to teething problems'. Indeed, while this might be true, the strength of the morphogenetic sequence as a methodology that 'tracks' change is such that while the data collected and the events represented a 'snap shot' in time, the methodology allows one to look at prior sequences as well as future sequences. As has already been mentioned the third year offerings were not substantially improved the following year. More crucially however in the fourth year the cohort following the one under study had a failure rate of thirteen percent, and all the failing students were black (Refer to Appendix A).

The foregoing discussion then raises questions about the possibility for change in this pedagogic context. There is a danger that if constraining contradictions continue to

characterize structural and cultural relations, agents, i.e. the lecturers, will continue to preserve themselves by defining projects that help them to realise their concerns, even if this comes at the expense of quality in teaching and learning. This means research imperatives, publications and ratings will continue to dictate what academics do, how much 'of themselves' they invest in the teaching and, because there is no systemic accountability, this is likely to lead to structural reproduction or morphostasis - both at the systemic level as well as lower down in faculties and departments .

While it may be too early to predict, the foregoing discussion points to the potential for a triple morphostasis. At the socio-cultural level, if constraining ideas are not challenged by the disempowered group – the black students in this case – they will remain marginalised in social interaction with no capacity either to organise for meaningful collective action or to personify appropriate roles as chemical engineering students. Additionally, the institutional structures, in remaining unchallenged (for example by academics who wish to protect their vested interests) will not necessarily impact faculty and departments to bring about change. This means in all three domains, reproduction is the result.

If the less tangible aspects of institutional culture are not addressed either by the institution or by departments and faculties, differences in success rates along class-racial lines will remain a 'dirty family secret'. It is likely that student experiences will continue to be differentiated along class-racial lines, with students moving through the system largely inhabiting very different worlds. The academy will continue to be 'research-active' and fail to give teaching its attention. The institution will continue to produce graduates who may possess all the visible material artifacts of success but who are disillusioned, misplaced citizens, attempting to reconstruct themselves in a new society not of their own making. Due to this, the face of the academy is unlikely to change; certainly not as rapidly as required by the university's stated commitment to equity. Instead it will continue to reproduce itself, which arguably does not bode well for dreams of a transformed society.

Chapter 9
Conclusion

The study sought to understand the reasons for the differential success rates in the Capstone Design Project in a chemical engineering programme at UCT. In the history of the course the failure rates have ranged between eight and twenty-two percent, with most of the failures being black students. This was of great concern to the academic staff in the Department of Chemical Engineering, particularly with intentions to improve both throughput and the student experience. In thinking through the cause of the problem, two dimensions were identified. Firstly, it was thought that the Capstone Design Project, in its design, did not promote success. Secondly, it was thought that something else prior to the Capstone Design Project, relating to students' design education experiences, was contributing to the phenomenon. In order to investigate these issues, a longitudinal study was designed which sought to follow students from the start of their design education to the end of the Capstone Design Project.

Students in the second semester of their third year enrol for several core courses including a design project, the Third Year Design Project, aimed at foregrounding design aspects of two of the four core courses. This is the students' first introduction to rigorous chemical engineering design education. This design education culminates in a design project in the students' fourth year of study, the Capstone Design Project. The Capstone Design Project is the culmination of the degree in which concepts and skills are drawn together. To a large extent the different aspects of the Capstone Design Project are taught as separate courses in the previous years and students are then expected to combine these in the final year design project. This expectation assumes that they have understood the fundamentals of each course to the extent that they know what knowledge from each course is relevant and how to use that knowledge. Speaking in Bernstein's terms, an expectation is placed on students to produce legitimate design text by being able to distinguish between the different courses that are part of the curriculum and to then produce text appropriate to the design context.

This study was, therefore, an investigation into the design pedagogy that the department made available to the students. If the final year design project is the culmination of the degree which is used to assess the outcomes of the entire chemical engineering curriculum, then the pedagogic practices leading to that assessment event needed to be looked at closely. Furthermore, the manner in which the students engaged with the design, their experiences and efforts towards producing legitimate text, needed to be understood.

In broad terms, therefore, the two dimensions of the problem meant the study was approached both from the lecturing practices and curriculum design as well as from the students' responses. In this way it was concepualised as a problem of both structure and agency. Margaret Archer's social realism was chosen as the theory that would allow me to give due attention to both the properties of the pedagogic practices and the students' personal properties and so to give a full(er) account of the process entailed in producing legitimate text. In the theory students were viewed as human beings with properties such as reflexivity, cognition and self consciousness, and with the power to mediate constraining situations in order to realise their concerns and projects. Through Archer, it was possible to analytically separate structure and agency through the idea of analytical dualism. Moreover, through her concepts of morphogenesis and emergence, it was possible to talk about structural and cultural conditioning, as well as and social and cultural interaction. Bernstein's concepts were helpful in describing those conditioning structures.

A sample of seventeen students was chosen for the study. The data collection phase spanned three semesters and in each of these, pedagogic practices were observed, interviews were conducted and students' text productions were accessed. The Chemical Engineering Department, located at UCT, a South African Higher Education Institution, meant the department held certain values and ideas about student learning in general and about design education in particular. The study was undertaken against the backdrop of curricular changes which were intended to realise the department's ideals about the

best way to offer design education to the students. These curricular changes and their enactments through pedagogic practices were viewed as conditioning situations.

Through Archer's theoretical contribution, it was possible to conceptualise student agency, whether individual or collective, as their deliberative efforts towards realising their concerns and projects in the light of constraining structural and cultural situations. It emerged here that while all students were constrained by particular pedagogic practices in the Third Year Design Project and in Process Synthesis and Equipment Design, black students were further constrained by properties of the cultural system in which ideas held by their student colleagues about the relationship between academic performance and race served to disempower the black students. The study also showed that elements of the Capstone Design Project were problematic in terms of unclear evaluative criteria. Therefore, with respect to the two dimensions of the problem mentioned at the start of the chapter, it seems that indeed the problems lie both with the Capstone Design Project, as well as students' design education experiences prior to the Capstone Design Project.

Bhaskar's notion of the stratification of reality, and the related tool of retroductive reasoning meant an explanation could be put forward for why the pedagogic practices did not live up to the academic staff's intentions. Using Archer's conceptualisation of structural and cultural dynamics, the study showed that academic staff members operate in an environment of constraining contradictions. As academics, they are mandated to both teach and to conduct research, among a range of other responsibilities that form part of that role. In reality however they are only valued for their research contribution to the institution. This creates a situational logic of correction in which they commit to their research agendas - for productivity in this area ensures promotion and upward mobility - but then do not have the time and other resources to be as productive in their teaching. As a result, even those departments which are in fact committed to teaching are not always in a position to realise their ideals because the environment does not support this.

There is scope for more research which considers the theories of Basil Bernstein within the critical/social realist paradigm. Given the criticism leveled at Basil Bernstein for being

overly structuralist, the question of interest would be to understand whether his theories are indeed deterministic or whether he does in fact account for the interplay of structure and agency in a non-conflatory manner.

This research has several implications for practice. There needs to be recognition that lecturers' activities are conditioned by issues at the structural level of the institution. It needs to be recognised that social and cultural issues also have the potential to constrain both what students and lecturers can do. Due to this, student learning issues cannot be addressed by 'tweaking' practice here and there. To ensure sustainable change, issues need to be addressed at the systemic level as well, and interventions need to feature at all levels. While it is true that agents can always act against their vested interests, the study suggests that if change at the systemic level does not occur, it is possible that over time structural and cultural morphostasis will be the result, with negative consequences for the state's and the institution's purported goals of equity and transformation.

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APPENDICES

Table 9: **Failure rates in the Capstone Design Project**

Year	Class size	No failed	Percentage	White	Black	Other/Unknown
2000	73	16	22%		14	3
2001	64	11	17%		8	3
2002	57	13	23%		13	0
2003	36	8	22%		7	1
2004	41	5	12%		4	1
2005	49	6	12%		5	1
2006	71	6	8%	1	5	
2007	71	5	7%		5	
2008	79	9	11%	1	7	1
2009	83	6	7%		6	
2010	61	8	13%		8	

Example of ethics discussion at the start of the interview

Interviewer: Feel free to ask me to clarify. There are no right answers; feel free to talk as much as you like. Everything is confidential. So on writing this up, in other words what you say, I'll pick a pseudonym for you, so I won't use your real name just to protect your identity. (Interview 1 with Mike)

Interviewer: everything is confidential. And so because what you say will be used in research I'll give you a random name; so it's not going to be your name used, I'll make up a pseudonym so that you are protected. (Interview 1 with Nandipha)

Year 2 First Semester 4th Year Planner

Wk	Dates	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	4049 Contents*
1	16 – 20 Feb	4049 – Mr McAvoy x 2 *Bus Soc & Enviros*	4049 – Mr McAvoy x 2 *Bus Soc & Enviros*	4049 – Mr McAvoy x 2 *Bus Soc & Enviros*	4049 – Mr McAvoy x 2 *Bus Soc & Enviros*	4049 – Mr Denver x 2		BFD to PFD, Flowsheet development, column sequencing
2	23 – 27 Feb	4049 – Mr McAvoy x 1 *Bus,Soc & Enviros x 2*	4049 – Mr McAvoy x 1 *Bu, Soc & Enviros x 2*	4049 – Mr McAvoy x 1 *Bus Soc & Enviros*x 2 **Project 1(P1) brief**	4049 – Mr McAvoy x 1 *Bus Soc & Enviros x 2*	4049 – Mr Denver x 2		
3	02 – 06 Mar	4049 – Mr Denver x 2 *Bus Soc & Enviros*	4049 – Mr Denver x 2 *Bus Soc & Enviros*	4049 – Mr Denver x 2 *Bus Soc & Enviros*	4049 – Mr Denver x 2 *Bus Soc & Enviros* **Project 2 brief**	4049 – Mr Denver x 2	**P1 submit**	Computer programme ASPEN
4	19 – 13 Mar	4049 – Mr Denver *Bus,Soc & Enviros x 2*	4049 – Mr Denver *Bus,Soc & Enviros x 2*	4049 – Mr Denver *Bus,Soc & Enviros x 2*	4049 – Mr Denver *Bus,Soc & Enviros x 2*	*Prof Comm x 2*	**P2 submit**	
5	16 – 20 Mar	4049 – Mr McAvoy *Bus,Soc & Enviros Process Control*	4049 – Mr McAvoy *Bus,Soc & Enviros Process Control*	4049 – Mr McAvoy *Bus,Soc & Enviros Process Control*	4049 – Mr McAvoy *Bus,Soc & Enviros Process Control*	*Prof Comm x 2*		Equipment selection, plant layout, utilities, materials of construction
6	23 – 27 Mar	4049 – Mr McAvoy *Bus,Soc & Enviros Process Control*	4049 – Mr McAvoy *Bus,Soc & Enviros Process Control*	4049 – Mr McAvoy *Bus,Soc & Enviros Process Control*	4049 – Mr McAvoy *Bus,Soc & Enviros Process Control*	*Prof Comm x 2*		
7	30 – 03 Apr	*Process Control*	*Process Control*	*Process Control*	*Process Control*	*Prof Comm x 2*		
06 - 10 Apr - **Mid Semester break**								
8	13 – 17 Apr	*Process Control*	*Process Control*	*Process Control*	*Process Control*	*Prof Comm x 2*		
9	20 – 24 Apr	4049 – Mr McAvoy x 2 *Bus, Soc & Eviros Process Control*	4049 – Mr McAvoy x 2 *Bus, Soc & Eviros Process Control*		4049 – Mr McAvoy x 2 *Bus, Soc & Eviros Process Control* **Project 3**	*Prof Comm x 2*		Design case studies, process control philosophy

					brief			
10	27 – 01 May	4049 – Mr McAvoy x 3	4049 – Mr McAvoy x 3	4049 – Mr McAvoy x 3	4049 – Mr McAvoy x 3		**P3 submit**	
11	04 – 08 May	*Bus,Soc & Enviros x 3*	*Bus,Soc & Enviros x 4*	*Bus,Soc & Enviros x 3*	*Bus,Soc & Enviros x 4*	*Prof Comm x 2*		

Table 10: Capstone Design Project schedule

Monday 16-Feb-09 **Design topic**		Wednesday 15-May-09 **Group allocation + Introduction to Research**		Friday 12-Jun-09 **Project proposal**
Monday 15-Jun-09 **Working on individual hand-ins**				Friday 17-Jul-09
Monday 20-Jul-09 **Hand-in 1st two reports on flowsheeting and unit design**	Tuesday 21-Jul-09 **Oral presentations Flowsheeting group A-G**	Wednesday 22-Jul-09 **Oral presentations Flowsheeting group H-N**	Thursday 23-Jul-09 **Oral presentations Flowsheeting group O-U**	Friday 24-Jul-09 **Class feedback Flowsheeting**
Monday 27-Jul-09	Tuesday 28-Jul-09 **Oral presentations section design group A-G**	Wednesday 29-Jul-09 **Oral presentations section design group H-N**	Thursday 30-Jul-09 **Oral presentations section design group O-U**	Friday 31-Jul-09 **Final Hand-in Flowsheeting/M&E-balances; Class feedback individual section desing**
Monday 03-Aug-09	Tuesday 04-Aug-09	Wednesday 05-Aug-09	Thursday 06-Aug-09	Friday 07-Aug-09 **Final Hand-in individual section**
Monday 10-Aug-09	Tuesday 11-Aug-09	Wednesday 12-Aug-09	Thursday 13-Aug-09	Friday 14-Aug-09 **Hand-in plant-lay out/ancillary equipment**
Plant-lay out and ancillary equipment				
Monday 17-Aug-09	Tuesday 18-Aug-09	Wednesday 19-Aug-09	Thursday 20-Aug-09 **Group presentations on economic and environmental analysis group A-J**	Friday 21-Aug-09 **Group presentations on economic and environmental analysis group K-U**
Economic and environmental analysis				
Monday 24-Aug-09 **Class feedback Economic and environmental analysis**	Tuesday 25-Aug-09	Wednesday 26-Aug-09 **Final Hand-in Economic and environmental analysis**	Thursday 27-Aug-09	Friday 28-Aug-09 **Hand-in Executive summary**
Monday 31-Aug-09	Tuesday 01-Sep-09 **Individual questioning (group A-J)**	Wednesday 02-Sep-09 **Individual questioning (group K-U)**	Thursday 03-Sep-09 **Final presentations**	Friday 04-Sep-09 **Final oral examinations**

Process Synthesis and Equipment Design - PROJECT 2 MARKING CHECKLIST

In ASPEN file:
- Should be two different property methods: one for absorber (since it has electrolytes) and another for the rest of the flowsheet (since it has gases at high pressures and temperatures)
- Reactor stage inlet temperatures should not be < 450°C
- Reactor stage outlet pressures (check in the outlet streams from the three stages) should be 116.2/108.3/100.0 bar
- Check that Equilibrium Reactor is used with temperature approach of 15°C
- Check that the number of trays in absorber is reasonable (May have to check a few students to get an idea of the minimum for this)

On the PFD/stream table:
- There should be **only one** reactor (possibly with multiple inlet streams and/or cooling water coils)
- There should be a pump for the water feed to the absorber
- **No** mixer or splitter units – just a pipe tee
- No storage necessary – but do not penalise if it is included

On ASPEN **and** PFD/stream table:
- Check specs are achieved (18939 kg/h NH_3 produced; 21 wt% NH_3 (and NH_4^+) in product; 96% overall conversion of H_2 (or N_2); less than 1000 ppm(mol basis) H_2O in reactor feed.
- Outlet temperature of cooler (after reactor) should not be less than 30°C (unless a **good** reason given for how it will be achieved) – minimum ΔT should be discussed somewhere
- Absorber should be at high pressure (probably 100 bar)
- No pump necessary for absorber liquid product – already at high pressure
- There should be fairly small concentrations of CH_4, Ar, N_2 and H_2 in the liquid product
- There should be fairly small concentrations of H_2O and NH_3 in the gas product
- Should be a compressor on the recycle line
- If a condenser is used to remove water, should be on the recycle line downstream of the compressor (unless a **good** reason is given otherwise)

Overall
- Consistency of stream table with ASPEN file

3. Discussion/justification of thermodynamic method(s)

Checklist

- The thermodynamic method used for the reactor, etc. (, i.e. high pressure, high temperature, etc.)
- The thermodynamic method used for the absorber (, i.e. electrolytes, etc.)
- For the absorber, the components designated as Henry's components

- Discussion reflected in ASPEN model

4. Discussion of reactor optimisation

Checklist

- Reasons for three-stage reactor with inter-stage cooling (exothermic equilibrium reaction, inter-stage cooling leads to lower temperatures which improves reactor conversion)
- Cold-shot cooling minimises energy (utility) usage
- Cooling with utility (cooling water) ensures that you can achieve 450°C in reactor inlet
- A description of how the above two considerations were played off against each other [Note that this will depend on what the student was able to achieve]

5. Analysis of wash water system

Checklist

- The sensitivity analysis of recycle ratio vs. wash water temperature
- The impact of the wash water temperature on the amount of water in the recycle stream and thus in the reactor feed.

6. Discussion of purge gas composition

Checklist

- A statement about the concentration of ammonia and whether it is acceptable from a safety and environmental standpoint
- More than one method to reduce ammonia in the purge (e.g. lower wash water temperature; increase purge ratio; add a sub-ambient condenser; etc.)
- A brief qualitative discussion of economic implications

Process Synthesis and Equipment Design - PROJECT 2 MARK ALLOCATION SHEET

1 and 2. Process Flow Diagram/stream table/equipment duties

Mark table

Mark	Description
0	No submission
1	Serious errors and/or omissions
2	Many errors and omissions
3	All major equipment included but some minor omissions in PFD and/or inconsistencies in stream table
4	All equipment included. A few minor errors.
5	All equipment included. All values in stream table consistent.

X 5 =

Comments

3. Discussion/justification of thermodynamic method(s)

Mark table

Mark	Description
0	No discussion
1	Discussion of only one method
2	Discussion of two methods but insufficient justification
3	Discussion of two methods with sufficient justification but without reference to Henry's components OR discussion of all three issues but with insufficient justification
4	Discussion of all three issues with minor gaps in justification
5	Thorough discussion of all three issues with good justifications

X 3 =

Comments

4. Discussion of reactor optimisation

Mark table

Mark	Description
0	No discussion
1	Serious omissions in the discussion (e.g. two of the above omitted) and/or serious logical misconceptions
2	Insufficient discussion (e.g. one of the above omitted) and/or logical misconceptions
3	Logical but with gaps in discussion and no additional creative insights
4	Thorough discussion of all aspects but without additional creative insights OR gaps in discussion but with additional creative insights into achieving the best system
5	Thorough discussion of all aspects and additional creative insight into achieving the best system

X 5 =

Comments

5. Analysis of wash water system

Mark table

Mark	Description
0	No discussion
1	Discussion on recycle ratio sensitivity omitted (unless discussion on water in reactor feed is very good then can get "2")
2	Discussion on water in reactor feed omitted OR insufficient discussion and poor logic
3	Discussion on both aspects but some gaps in argument
4	Thorough discussion on both aspects OR discussion on both aspects, and additional aspects, but with some gaps in argument
5	Thorough discussion on both aspects, and additional aspects OR exceptional discussion of both aspects

X 5 =

Comments

6. Discussion of purge gas composition

Mark table

Mark	Description
0	No discussion
1	Poor discussion and/or multiple omissions
2	Insufficient discussion OR only one method to reduce ammonia OR another of the above aspects omitted
3	Satisfactory discussion of all aspects (at least two methods to reduce ammonia)
4	Thorough discussion on all aspects (at least two methods to reduce

	ammonia)
5	Thorough discussion on all aspects (at least three methods to reduce ammonia)

X 2 =

Comments

General

Take off 5-10% if: (a) presentation is not professional; and/or (b) instructions in the handout are not followed (e.g. maximum number of pages in each section, font type and size, line-spacing, appendices not referred to in main body; etc.).

Comments

TOTAL/100 =

Process Synthesis and Equipment Design: PROJECT 3 MARK ALLOCATION SHEET

The mark allocation for the various sections will be as follows:

1. Executive Summary – 30 marks.
2. Design Report – 100 marks.
3. Design Basis – 10 marks.
4. Process Description – 25 marks.
5. Process Flow Diagram – 25 marks.
6. Flow summary table (ASPEN Mass Balance) – 20 marks.
7. Utility flow diagram (UFD) – 20 marks for completeness and correctness (including sizing).
8. Boiler and Cooling Circuit mass balance and discussion – 30 marks
9. Utility summary table – 20 marks.
10. Process control strategy for ammoxidation reactor and crude acetone distillation column – 20 marks.
11. Process Control Diagram (PCD) for oxidation reactor and crude acetone distillation column - 20 marks
12. Equipment specifications – 70 marks.
13. Detailed calculation and specification of one pumped liquid line – 10 marks.
14. Calculation and specification of control valve and relief valve – 5 marks each (, i.e. 10 marks overall).
15. Preliminary Site and plant area layout plan – 20 marks.
16. Preliminary pipe routing for process streams– 10 marks
17. Preliminary pipe routing for steam header and cooling water ring main– 10 marks
18. Environment and Safety – 30 marks.
19. Capital and Operating Cost Estimate – 50 marks

Note that these marks add up to more than 500. This mark will then be divided by 5 to get a percentage before the “2n!-rule” for lateness is applied.

Comments on what was expected in project three

I have moderated every project to ensure consistency in the marking of project 3. Most of the marks were left unchanged after my moderation. A few of the projects marks were increased during moderation. These were usually as a result of poor presentation of the report where the information was not easily accessible and had to be searched for. Moderation also resulted in a couple of projects being marked down to ensure consistency of the marking process.

I am going to present some general comments on the project as a whole and then discuss some specific points on each of the sections, offering you guidance on how to improve in these sections in your final design.

General Comments

Your design brief was to design a plant to produce 200 000 tpa of phenol. That was the point of the project. Making sure that you produced that production target was vitally important. This was the whole purpose of the design. If you did not produce the required production target, you actually failed the design project. I had accidentally left in my calculated value for the cumene feed, but it provided me with an interesting assessment of your approach to the project. This value was not supposed to be the value you used. It was not given in the design brief, i.e. design a 200 000 tpa phenol plant using 330 kmol/hr cumene feed. That is a different design problem. Make sure that your design meets the design requirement.

There were some excellently constructed project reports, and some which looked as though they had just been slapped together on the morning of the hand-in. The report gives the reader an impression of the quality of the work produced. Make sure that your report creates a good impression with the reader. This improves your credibility. Take the time to order your report and do include a table of contents, with page numbers, such that the information the reader may desire to find is accessible. You were given a guideline on what should be included in the report by the mark allocation. I feel that I should have included marks for presentation of the report and will do so should I be involved in this project next year. You are about to graduate as a professional person, and taking the time to make the presentation of your information accessible says a great deal about your professional attitude towards life. Take the time on your report and make it a good easy readable and accessible report.

Then there is the question of what should be presented in the report and what should be included in the appendices. Try and keep the report as clear and crisp as possible, but it is rather annoying to have “this is presented in Appendix xyz” for information you would like to find in the report. Make your report self standing, i.e. it should be able to stand on its own as a complete work. Present supporting information in your appendices. Examples are detailed calculation should be presented in the appendices, data sheets, PFD’s, mass balances, UFD,
summary tables, should be at the beginning of the appendix, or in the main body of the report.

Put important information in the body of the report and supporting information in the appendices.

Use page numbers on make sure that they are consistent with the table of contents.

Do not repeat information in the body of the report, or present it in the body and repeat it in the appendix. Make your report and appendix clear of repeated information. Also make sure that if you put information in an appendix, be certain to include it in you report.

Now, some comments on specific sections of the project reports.

Preliminary Mass Balance and BFD

The objective here was to get you familiar with the flowsheet and so that you got an ideal of the size of the project. I may have created a red herring by leaving my calculated feed rate in the spreadsheet I gave you. You should have used your initiative here. Yes, you are required to think about this!!! You could easily have increased the feed rate to produce the desired production of phenol. I gave you a spreadsheet with the desired output format and a copy of the block diagram, so there was no excuse for you not getting all the marks on offer there. It just showed again that you need more practice in doing mass balances.

Design Basis

This was particularly poorly covered. The design basis is the basis from which you design your equipment. How does this compare to the equipment specification sheet? Well, the spec sheet covers the engineering details of the specific piece of equipment such that the equipment can be purchased or manufactured. The design basis should have all the information which you used in the design of the equipment, which means that it must be pretty detailed. I was expecting that you would take the design basis I gave you in the handout and complete it for every section of the plant. The design basis I included in the project brief was such that you could do the mass balance. I found it strange that many people though that all they needed to do was to re-present the information I had given you for full marks.

So, what information should be in the design basis? For every section, e.g. the final acetone column, you should include pertinent information for that section. Information specific to the whole design should be included in the general section. So for a typical distillation column, the following information should be included:

- Feed rate, composition, temperature, pressure, density, viscosity etc.
- Gas phase density, and any other information required for the equipment design

- Column operating conditions e.g. temperatures, pressures, reflux ratios, reboiler and condenser duties, utilities consumed e.g. 2.5 barg steam in the reboiler (and quantity) etc.
- Type of equipment used e.g. partial or full condenser on distillate, kettle reboiler, types of trays etc.
- Recoveries to bottoms and distillate
- Product flows and composition.
- Any special considerations e.g. for the reactors you need to consider the explosion limits of the reactor off-gas mixture

The utility sections should also be summarised in the design basis.

So, you can see, there is a fair amount of information which needs to be included in the design basis of a plant like this.

Process Description

This section was reasonably well answered. I offer the following suggestions to improve your process descriptions.

- Try and present as much process information in the process description as possible, Mention temperatures, pressures, and other pertinent operating parameters and give the desired value.
- Describe the type of equipment you are using e.g. if you are using a 69 tray column with bubble caps and a feed on the 35th tray, product take off on the 12th tray, kettle reboiler and partial overhead condenser, say so. Describe the process and the equipment.
- Refer the reader to the PFD where the section you are describing is represented diagrammatically.
- When describing reactions including organic chemicals, use the structure of the chemical and include the name of the chemical under the reaction equation. Remember that many reactions are reversible, and you should know which are and which aren't. Never just include the names of the chemicals as a representation of the reactions. In the narrative, discuss the extent of reactions and side reactions.

Process Flow Diagram

The PFD's were mostly given to you in the project hand-out. You were expected to take the pfd's you were given and bring them up to the required standard. I specifically asked that they be sub-standard so that I could evaluate your final products. One of the major omissions from your PFDs was the inclusion of utility streams to each and every heat exchanger. You need to include these utility streams to complete the pfd. To create enough space, you would have

been well advised to split the acetone and phenol circuits into 2 pfds. This would have been a neater presentation. Some errors on the pfds include:

- Omitting equipment numbers
- The utilities
- Connections to equipment of flow lines
- Having heat exchangers in the suction lines of pumps
- Not including reflux drums
- Not considering storage of feed streams or products or for plant operability

Flow Summary Table

In the design brief you were given explicit instruction as to what to include in the flow summary table. I had given you a block diagram which was to be used for the excel mass balance only. You had the full right to change the stream numbers for the flow summary table. But these had to correspond to the stream numbers on the flowsheet. The streams form the block diagram were the minimum which should have been presented in the flow summary table. You were asked to name the streams and give stream numbers, pressure, temp, phase, molar flow and composition, mass flow and composition and the total molar and mass flows. We were very harsh on projects which did not produce the required quantity of phenol (200 000tpa). I had specified the operating shifts, no of days etc such that the class all designed on the same basis and we did not have to check each and every mass balance. You still needed to meet the design spec.

I was not hard on significant figures in the flow summary table. Prof van Steen wanted us to fail everybody who did not present their tables with the appropriate number of significant figures. Be warned, Prof van Steen is one of the markers of the design project.

Utility Flow Diagrams

We were expecting a UFD for steam, cooling water, compressed air, sulphuric acid and the refrigeration circuit. We did not expect electricity. Additional circuits which could have been included were water reticulation, diamine, sodium hydroxide. The storage of the reagents and products could be included in the utility sections, or on the PFD as appropriate.

We expected that the UFDs included the circulation of the utility through the plant and incorporated the additional equipment required to do this. Take for example the cooling water circuit. The UFD should include the cooling towers, tag from the water circuit for cooling water make-up, a pump to distribute the cooling water through the plant, tags for each consumer (or representations of the consumers) and return tags from each consumer, a tank to receive all the return streams and a pump to feed the cooling towers. You could have a tank on either side of the cooling towers to improve the operability of the cooling water section.

For the steam circuit, the UFD should include a boiler feed tank, tag for boiler feed water make-up, boiler feed water pumps, boiler, tags for coal and ask, a distribution network for each of the consumers of the various pressures of steam, returns from the consumers as appropriate. Please note – you do not compress the steam to a higher pressure, rather you produce the steam at the highest pressure and let it down to the lower pressures. This let down of steam can be through a turbine (but only if you want to generate electricity from it) or you could use pressure control valves controlling the pressure up-stream.

The refrigeration circuit would be a closed circuit for the refrigerant which would interchange with the circuit of the cooling solution e.g. brine of glycol. You would used the refrigeration loop would have a heat source which corresponds to the heat sink of the brine circuit.

For reagents which are purchased as concentrated reagents and used as dilutes reagents in the plant, a storage tank showing a tag for receiving the reagent, pump to distribute the reagent and the mixing station of the reagent. For sulphuric acid, I would have used an inline mixer to get the required concentration of sulphuric. This generates a fair amount of heat which will need to be removed from the solution.

The general PFD standards should be maintained for the UFDs, i.e. streams entering on the left and leaving on the right, not the bottom!!!!

Utility Summary Table

What was expected here was a table, ordered by utility type e.g. HP steam, summarising the consumers of the utility and the total consumption of that utility. So, for the boilers, your summary table should have looked something like this:

Utility	Consumer	Consumption (kg/hr)
HP Steam	100HX01	150
	100HX02	200
	400HX07	350
Total		700
MP Steam	200HX02	1000
Total		150000
LP Steam	100HX07	12500
Total		175000
Total Steam Consumption		325700
Boiler Blow-down (10%)		32570
Boiler Capacity		358270

I am sure that you get the picture. You would then produce such a table for each of the utilities and summarise the total consumption of each utility in a final summary table as follows:

Utility	Consumption (kg/hr)
Steam	358270
Cooling Water	
Water	
Compressed Air	
Sulphuric Acid	
Diamine	
Refrigerant	

Process Control Strategy

This section was not well handled by many of the project teams. I would like to give some pointers as to what I expected in the process control strategy. I expected that a control philosophy be constructed for a specific column and that a process control diagram is drawn depicting the control strategy.

Control Philosophy

The control philosophy should begin with a summary of the process. This document is meant for the instrumentation engineers who know little about the process and need a brief introduction as to what is happening in the section they are about to design the control system of. Include a process summary which includes the parameters they are controlling and the temperatures and pressures at which the unit operates.

There are two types in instrumentation which can be included in a control system. Those variables incorporated in control loops and the variables for process information, alarms etc. Handle each of these types of variables separately.

Control loops

Include a description of each of the control loops stating the reasoning behind the control strategy. Indicate the set points to which the loop will control the controlled variable. Indicate whether any alarms will be required for the loop to alert the control room operator of a deviation from the desired set point. State the set point for the measured variable e.g. this control loop will control the level in vessel 400TK03 to 50%. Each control loop should be numbered. The response of the controller to a specific upset should be included in the narrative. The failure position should also be noted e.g. this control valve should fail closed, or this control valve should maintain its last position in the case of failure. The other option is to fail open. The dynamics of the control loop should be explained in detail. E.g. the flow rate of the feed to the reactor is measured by a flow element, the flow element transmits the value to the control system which compares the measured variable to the set point specified by the

Control room operator and adjusts the control valve FCV 07 accordingly, opening to increase the flow, closing to decrease the flow.

Measured Variables
Measured variable such as temperatures, pressures, flow rates, etc. may not be part of a control loop, but provide valuable information as to the performance of the plant. The measured variables can give you the answer as to why the condition in a control loop is not being met e.g. the flow rate in the feed line is not reaching the desired set point because the pressure in the feed line is very low indication that the section operator should investigate the pump etc.

These measured variables may be connected to alarms to alert the process operators of specific conditions in the process. For alarms, indicate the level of deviation from the set point which constitutes each level of alarm e.g. when the tank reaches a level of 25% signal a low level alarm, at a level of 20% signal a low low level alarm.

Process Control Diagram
A PCD is a PFD for the section of the plant with the control system added. This means that the PCD should be produced to the same standard of a PFD. All the ancillary equipment should be in their place. For the column, the column, overhead condenser, reboiler, overheads pump and bottoms pumps should all be included. Each piece of equipment should have an equipment number corresponding to that on the PFD.

The control loops and measured variables should be depicted on the PCD as described in class. The desired values of each of the controlled and measured values should be included on the PCD for easy reference.

Equipment Specifications

For the equipment specification, a sample calculation of how the equipment was sized should be included, with appropriate explanatory notes and justification. The equipment specification sheets (Data sheets) should be presented for each and every piece of equipment on the PFD and UFD. It is useful to present the spec sheets per equipment type e.g. pumps, heat exchangers, etc. grouped by area. The data sheets provided provide the basis for these spec sheets.

Pumped Liquid Line (one)

Here the calculation was generally well done, but to do a proper specification and calculation, you need an isometric drawing of the line. Only 2 groups produced an isometric diagram for their pumped line. You could have done this going back to first principles, but the short cut method of equivalent line lengths for valves, bends and other fittings is more appropriate. I think it is called Cranes method.

I trust that you will find these comments useful and have learned for the analysis of your project.

Third Year Design Project marks

Student	Population group	Third Year Design Project marks
Brian	White	79
Devon	White	72
Gontso	Black	44.5
Kathleen	Chinese	32.4
Katleho	Black	42
Kelly	White	78.5
Mike	White	98
Nandi	Black	32.1
Nazlee	Coloured	27.3
Nolwazi	Black	68
Petrus	Black	71.5
Tanya	Coloured	80.4
Tariq	Indian	79.5
Taryn	White	68.5
Tasneem	Coloured	33.7
Thabang	Black	58.5
Zunaid	Indian	61.5

Example of interview prompts

Interview 1 – Year 1
Introduction

Thank you very much for agreeing to do this. This session is the first of three as I indicated on the email. All three interview sessions essentially address the main research question for the PhD and the sort of formal title at this stage is 'How does student agency mediate the production of text in chemical engineering design?' Put simply it really is about how your individuality contributes to your engaging with design; both I guess in the narrow sense of chemical engineering design the course as well as just the nature of design in general. And so each session has specific questions dedicated to that session. So for instance today is really about getting to know you a little bit. The next session will still be about getting to know you but in the narrow sense of the academic side of things and then the last session will try and pull things together. And the final session, well the final for this year anyway, will be centred quite strongly on how these first two sessions go. Just to let you know that everything is absolutely confidential. What you say will be used in the research but you will be given a random name. So it's not going to be your name used, I'll choose a pseudonym so that you are protected. And of course if I ask you a question and you're not quite sure what I'm asking you feel free to say 'I don't know what you're talking about', 'or please repeat the question' or whatever. So the first question for you is what concerns you at this stage in your life? Or to make it clearer, what sorts of things keep you awake at night…give you grey hairs?

Talking through those pressures is it because you are worried about what other people might think or is the pressure just due to the work?

Where do you want to get to in life or what things do you want to achieve?

So you are now a third year student, do you have a sense of the things that have enabled you to get to where you are or things that have constrained you, not just academically but in every sense you can think of?

The people that you've asked for help this year, are their answers the sort of answers that you kind of think 'Wow that opens u a lot for me'. In other words, are they giving you almost a world view so to speak or are they just giving you the help for that problem specifically?

So they don't work from what you've produced and rationalize from your own….understanding?

Do you notice, if you do, is there a pattern in terms of who twigs on in terms of this engineering thinking, and how the help is distributed to people, if that makes sense? So

tell me about the networks of people who help each other out and the people who get it and those who don't.

Oh okay but then you're having to do the job, or are you having to do the job of trying to…

Do you get to verify the rightness of the one versus the other among your lower down group then…?

The other thing now is, what I want you to think about, you said earlier about being pressurized and that you goal is to get to fourth year, when you plan your life now, how much of your planning revolves around your work?

If for instance you've decided you've had enough, and decided to break the pattern, heaven forbid, but say you decided to walk along camps bay beach or something, would you really obsess over that decision and the opportunity cost etc…

Okay, now to change direction a bit, when sitting in lectures, do lecturers ever model something to you that you think you can take on and it appeals to you either in terms of how they lecture or what they say?

Earlier you made reference to the fact that you work with people to try and work through problems, so when you started third year your goal presumably was to get through third to fourth year, that I gather did not work that way, so in determining your next plan of action, are you likely to consult others or do you make decisions and then carry them out without consultation?

So even if the person who you asked did not necessarily agree with you are you saying that it would not necessarily stop you…or…

Do you ever have conversations in your head, do you ever have that experience….

You talk about the different you's and how the one maybe sees the error of the other one and so on, what sets these different you's apart do you think? Are they different phases in your life, different ages, different experiences?

In terms of the second session, the stuff that we've spoken about now is not just going to disappear. So the next session will be in around two to three weeks and as far as I know by then you'll be doing the design project. By then you would have submitted two assignments but have got back two submissions. So the intention there is to look at those submissions, which according to Prof Strauss need to be good in order for you to proceed with the rest, and to see whether he has given you feedback and comments on that submission. Further to that I would be interested to know whether you are able to take that input forward to the next submission in correcting any errors identified by him. This

is not a value judgment but about how you're constructing the idea of design. And I hope that is okay with you; that you won't feel violated when I look at your work. That is all for today, thank you.

Interview 2 – Year 1
Introduction

Thank you for coming through again. This session is about the academic side. In general terms there are a number of messages that lecturers send to you in different media in lectures, tests or whatever and you read things there and work with that material in different ways. So today is about me trying to find out more about that specifically in the context of design. So my first question is, what is your idea of design or how would you define the design process?

This design brings together Separation Processes and Reactor Design II and so how have you used Reactor Design II in your design project?

When you had to do your, had to design you distillation column in your project, had you been introduced to that in Separation Processes already so that you knew what to do?

So apart from the apparent inconsistencies in the feedback sessions and the apparent links between the Third Year Design project, Reactor Design II and Separation Processes, what do you think makes the project challenging or difficult?

Okay tell me about test week, how did that go?

Okay so now presumably while you're working through the design you're working with some people on some level. What are the kinds of common questions that arise? What are people asking each other?

And are these messages that you are getting from those consultations consistent?

What about the level of computing in the design, how is that?

Okay that's great thank you.

Interview 1 – Year 2
Introduction

Okay, basically I'm still interested in how you learn design. At the start of last year I asked you what design is. You've now gone through Process Synthesis and Equipment Design and I want to then put the same question to you.

And Process Synthesis and Equipment Design, how has that been?

The integrated system in fourth year, are you enjoying that and is it working for you at all?

And the process control lectures?

With respect to the three projects in Process Synthesis and Equipment Design, apparently the first two were individual and the third was a group project, how did you, you mentioned earlier in terms of Mr McAvoy that you found it difficult to know what it is that he's looking for. So was that your experience of project one?

And the comments in the first project, did you find that they were useful? Were they comprehensive and useful?

And project three, how was the group dynamic for your group?

When you say before you mean in previous years?

Did you receive the feedback sheet when you got your projects back?

So before you did your project you didn't….

The mark sheet and the other things, do you only have hard copies?

Now the next time I am likely to catch you will be at the end of the Capstone Design Project because before then I expect you guys will be quite hectic. So that final interview will be about reflecting and seeing whether you have been prepared and have been given the ammunition in your opinion to do Capstone Design Project. So that is all for now. I just wanted to have an idea of how this semester has gone for you.

Thanks and all the best for all the exams.

Interview 2 – Year 2

This is now the last little bit, like a reflection of sorts, taking in the year and so on. You're almost out the door and knowing your personal capabilities, would you say that you met your expectations with respect to your performance in design, and if not why not, or what were some of the things that stood in the way of that?

What programme was it?

And did you try, I know that Prof Strauss likes Scilab as opposed to Matlab, for example, because it's supposed to be a lot easier to use, more user-friendly or whatever. Did you manage to get help on that, identifying what the issues were with your particular programme?

Okay, you said that you had to take a programming approach I mean was there another approach or was that your only approach?

Your final work was partly or you would have had an individual mark and a group mark, was your group mark better than your individual mark?

So you don't know what was wrong with your individual submission, or what didn't go so well?

Last year I was very interested in student collaboration in projects, and you've just made reference to the fact that you were hoping for a little bit of collaboration around the Scilab and the programming. How much of that collaboration happened in other aspects for instance your mass and energy balance or was that your sole individual effort?

At the end of last year I asked you about your use of Reactor Design II and Separation Processes given that it was a project that was meant to bring those two together. Now at the start of fourth year you were then introduced to heuristics, and I want to call the approach in third year fundamentals. So was your approach to the Capstone Design Project more around fundamentals or heuristics?

Right and throughout the design were you always sure of what you were being asked to do, were you always sure what you needed to do for each task?

How did you find your group, the group dynamics?

Would you say that design is an assessment exercise or a teaching exercise?

How were the design orals?

But now did you feel during the oral that things were not going well? When you say they didn't ask you much what do you mean?

And could you tell from their responses or from the way that they interacted with you, could you tell whether you were saying the right things or not or were they not giving much away?

My next question is about whether you think you were prepared but I think in considering design as an assessment exercise I guess on some level you felt that part of Process Synthesis and Equipment Design prepared you in that last project that you thought was most useful. So do you have any other comments in terms of design preparation? So were some things were more manageable and which things were these? Which things could you sort of just do and which things were a real struggle, I mean I suppose apart from the programming?

What is the one thing that made all the difference? If a person were to ask you 'What is the one thing that made the difference for you in terms of succeeding?' what would you say? What motivated you though, like I can't imagine it, if you've wanted a holiday since May, how did you get yourself through all the stuff after the eight weeks, how did you do that?

And right, so now that it's all over is there any one thing that should have been emphasized more early on to make this experience more manageable?

Last year one of my first questions to you was about your personal projects and concerns. I mean at the time you were getting ready to go overseas for vac work. You've come back from that and you said early this year that that was exciting and there was a possibility of an MSc but you weren't sure at the time so are you any more certain now?

But would you consider yourself the kind of person who consciously, say things aren't going well and you obviously want to succeed against odds, I mean are you the kind of person who's going to do all that you can to get to what you want despite the circumstance you find yourself in? Have you been in that sort of situation before?

Just to go over it again the fact that the mark wasn't as great as what you would have liked do you take full responsibility for that or do you think that, for lack of a better phrase, outside forces contributed?

Okay, thanks a lot. That's all that I wanted to know. I mean your reports get archived but I will look at them anyway from the perspective of the assessment. There were six people marking your work and so I want to know more about how that worked out. I really appreciate your participation in the study. All the best for your future and your MSc.

Example of a student interview

Interviewer: What are your concerns that keep you awake at night, things that worry you? They can be general things as well.

Nolwazi: I guess I can say chemeng, and then my family.

Interviewer: when you say chemeng, what does that mean? What is it about chemeng that worries you?

Nolwazi: third year, this year is very difficult for me but I wouldn't be able to say, for sure now for now because we haven't written any tests. But for now work is too much for me. I can't handle it. But ja, Separation Processes I guess and, but I think I'm having problems with Separation Processes.

Interviewer: are you enjoying it or are you not enjoying it?

Nolwazi: no it's not that I'm not enjoying. It's just, I don't understand it. Like this section that I'm doing, I don't understand it. So I'm not sure if the reason why I'm not understanding is I'm not enjoying it or just, I'm not getting the thing.

Interviewer: was it like that from the beginning or is it recent?

Nolwazi: it's recent, at the beginning it was fine but now it's becoming hard. With first semester work, when it was the last few weeks it was hard but now it's (only been) four weeks and already it's hard. So I don't know what to expect…too much work to do.

Interviewer: and then when you say family stuff, like what sort of family stuff.

Nolwazi: thing is at home like both my mom and my sister are sick like, so ja, it worries me.

Interviewer: do you get to talk to them at all during the term, during the week?

Nolwazi: ja most of the time I just talk to them. But I don't get that much time to talk to them.

Interviewer: and for how long have they been sick?

Nolwazi: no like the thing is my mom was diagnosed with cancer and my sister has been sick since, for a while now. So both of them (are sick).

Interviewer: who's there at home with them now?

Nolwazi: my mom and dad and my sister, they stay together…

Interviewer: and your dad is okay?

Nolwazi: ja my dad is fine.

Interviewer: okay, my other question is, is Separation Processes the only course you're worried about? I mean what else are you doing?

Nolwazi: Reactor Design II, Separation Processes, Solids….

Interviewer; how is Solids?

Nolwazi: solids I'm just like, I don't know what's going on. I'm just going. It's fine because I understand what's going on for now. I'm not worried about it. It's going fine. And then Reactor Design II, when I'm studying … this other weekend I was like studying it and then I did understand what was going on. So with it (Separation Processes) I guess I'm not sure what's going on. I'm not sure whether it's hard or what. The first time I studied the chapter it was fine but now it's becoming something else. I don't know. I don't know. Maybe if I try and study and get somebody to explain to me it'll be okay.

Interviewer: okay we'll get back to that just now. Second thing is, 'What are your dreams or things that you want to achieve both long term and short term?'

Nolwazi: okay, first of all, before we get to that question for now I'm so confused because I don't have a bursary and the thing is I don't know where to apply because I don't know which kind of industry I want to work at. This other time I took (biological processes) as my elective and I went to attend and the first lecture, I just didn't enjoy it. I said to myself 'Okay before I wanted to work for Unilever but now I'm not sure if I want to go and work there'. So for how I'm kind of confused about where I'm going with chemeng.

Interviewer: and are you still doing bios?

Nolwazi: I dropped it and I'm doing catalysis now.

Interviewer: and how's that going?

Nolwazi: I don't know what's going on with catalysis. We just listen to the dude and we just sit there and listen. I don't know what's going on. So I wouldn't know if I'm enjoying it or not. Maybe if I read my notes I will but I for now I can't decide.

Interviewer: and I noticed that Dr Smith in Reactor Design II started doing catalytic. Is that in any way related to what happens in your catalysis lectures?

Nolwazi: ya ya there is like a connection. So I guess if you're doing it (the catalysis elective) will help somehow.

Interviewer: right…and any other aspirations beyond what you've just mentioned now?

Nolwazi: Ey I guess, I don't know. I just want to finish chemeng now. Like before, in my first year, I really struggled. So now third year is putting me down because, I can't afford to be failing. I want next year hopefully to graduate. Ja so I just want, I guess that's it.

Interviewer: who's paying for you now?

Nolwazi: financial aid.

Interviewer: and they give residence and everything?

Nolwazi: ya, they give everything.

Interviewer: and they've been good and supportive, financial aid?

Nolwazi: they're alright I mean you're being paid for.

Interviewer: will you look for a bursary still or will you stay with financial aid?

Nolwazi: I was thinking of applying like for a bursary, and then I'll decide then. I have my option of looking for a bursary. Maybe I might like to work for them (the bursary company) but will do some research before applying because right now I'm already doing my third year and I already know where I want to work. In first year you just apply for some bursary and you don't know what's going on, and you end up working for some

company that you don't want. So for now I'm not. I should get a bursary where I know I'll want to work.

Interviewer: okay, and now can you give me a sense of what you think has made it difficult for you to get to where you are not only in chemeng but in life in general? I mean things about yourself maybe, about UCT or about chemeng…

Nolwazi: okay let me start with high school. I came from this other high school. They did everything for us. It was like 130 of us and you got everything that you wanted. If you started out you have the lecturers doing this for you; you get tutors. Then I got to UCT and things were different. You had to do everything yourself. If you're struggling with something you have to go through it yourself. You have to be the one to find someone to help you. So I think with first year they spoon feed us you really did not know how to handle things alone. And then with the other thing I guess, what can I say….

Interviewer: anything that you can think of in terms of your personality or whatever?

Nolwazi: (laughs) I guess sometimes I'm lazy. And I think, what can I say, you know how it is some people can study for like a long time. With me I can't study. Some people can sit for five hours. I can't do it. I can only concentrate for like an hour. In chemeng sometimes there is a time when you need to sit for like days and study. I can't do it. And before, in first year or second year, I was not used to working with most people. I would only go to people that I know, and with people that I didn't know I wouldn't even go and ask questions. So I guess that was another problem because with chemeng you need to know everyone.

Interviewer: do you tend to work with people now?

Nolwazi: ya. Right now starting from last year I started working with people. Even if I don't know the person I would ask 'Please explain, what's going on?' Unlike in first year (where) I would just ask my friends and if my friends don't know then I would say 'We all don't know'. Now I understand that I really need to work with everyone. You can't just pick this person and that person.

Interviewer: okay. So now how about the things that have enabled you to be where you are, things that have made this road a little more manageable?

Nolwazi: I guess support from my family. 'Cause my older sister is doing her Masters and she was kind of helping me when I was going through stuff. And then the other thing is I didn't give up. Even when I was in first year I was (already sick and tired of) chemeng. Oh gosh, I worked hard because I knew that at the end I wanted to get my chemeng degree. So I worked hard in order to get everything. I didn't give up. Then the other thing I guess is, ya, I don't know.

Interviewer: when you say your sister is doing her Masters, what is that in?

Nolwazi: she's doing biochemistry….

Interviewer: at UCT?

Nolwazi: no no no, at the University of Fort Hare.

Interviewer: so do you ever talk about biochemistry?

Nolwazi: ya ya sometimes she even takes me to her work to show me stuff.

Interviewer: do you find that interesting?

Nolwazi: not really. It's all right.

Interviewer: I don't think I asked you this earlier but why did you pick bios as an elective to begin with?

Nolwazi: that's the problem because you know I thought I wanted to work for Unilever and they make Handy Andy and I just pictured bios and Unilever and they go together. But then I got there and they started talking about … they mentioned things that I hated and I thought 'No!' Then I just deregistered from it. And then … maybe next year, when I don't have lots of work, maybe I'll enjoy it. We had presentations, prac, Reactor Design II and I just, and I guess that was the other reason why I did not enjoy it…

Interviewer: too much happening…

Nolwazi: ya and then I just had so many submissions and then she (the lecturer) started mentioning ATPs that I hated in high school and I just thought 'No!' so I took catalysis 'cause no (there are no) tuts, just lectures.

Interviewer: okay, give me your impression of the lecturing, what styles do you enjoy and what do you not enjoy?

Nolwazi: let's take Joanne Willis, I loved Joanne Willis. She knows how to explain. She can explain … she cares for you to understand instead of just giving you information and saying work around it. And then there's Prof Reed, he's too clever. When he says something he expects everyone to think it's like basic stuff that we should just understand it. I know that maybe for him (it's easy), but for some of us (it's not). He would just mention something and then the way he explains, he explains it deep. Something that is (as easy as) one plus one is equal to two, he makes it so complicated that we won't be able to understand it. Ya and then okay Dr Smith you can't hear him. His voice is … he's much better now but first semester I couldn't hear him. he was very very (soft). And then we started bringing ear phones. I had problems with my ears and I couldn't even hear what was happening. But I guess I would say Joanne Willis because the thing is she can explain to you. The way she lectures is different from other lecturers.

Interviewer: the lecturing that happens now do people use examples to explain concepts and if so does that help you or does that not make much of a difference to you?

Nolwazi: like when they talk about something, do they give an example?

Interviewer: yes

Nolwazi: sometimes it helps but sometimes you'll be in a lecture and you're tired and you get the examples and it helps if you're reading your notes. They help you when they give you a physical situation. With us sometimes Dr Smith will do a chapter and then afterwards he gives an example of what he expects in a question. ya so it really helps.

(I talk about second interview and pencil off)

END