THE PHENOMENON OF LEARNING: First year engineering students' engagement with chemistry Supplemental Instruction

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Vinodhani Paideya

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Supervisor: Prof. Reshma Sookrajh

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ABSTRACT

This study explores first year Engineering students' engagement in chemistry Supplemental Instruction sessions at a tertiary institution in South Africa. It offers insight into an institutional programme that attempts to provide support structures for Engineering students through the introduction of Supplemental Instruction (SI) as an approach to improve the quality of chemistry teaching and learning.

SI is an academic support programme based on collaborative learning principles. The study researches the role of Supplemental Instruction within first year Chemistry and its implications for teaching and learning in higher education. Its specific focus is on engineering students' engagement in constructing an understanding of stoichiometry concepts within the SI sessions.

The critical question that guided the study concerns how and why first year engineering students engage in the chemistry SI environment in the way that they do. This study makes use of a design research methodology in order to understand the engineering students' engagement within a Supplemental Instruction environment. Design research was selectively used to estimate the effectiveness of the SI intervention in engaging students with stoichiometry concepts. Two SI groups comprising students from two different engineering modules were observed and analysed over a period of 13 weeks. The research methods employed were observations through video recording, focus group interviews, individual student interviews and SI leader reflective journal entries. Fifteen SI sessions were observed and two focus group interviews were conducted, which served as the main data-gathering activities related to the research questions of this study.

Data revealed that student engagement in the educational social space is driven by the development of socio-scientific norms, pedagogical support and structural support. Social learning spaces encouraged explanations, conceptual understanding and reflective thinking in a collaborative learning environment. Data further suggested three broad themes describing students' engagement within the SI learning environment, viz. experiential, social and strategic engagement. Ideas from Engagement Theory and Phenomenology were borrowed to theorise the results of this study. While there is a suggestion that students acquire knowledge through learning engagement and experiential learning practices, which happen in different ways within a context of social learning spaces, it is argued that this study is significant in that, in spite of chemistry knowledge being regarded as fixed and completely isolated as a pure science having one truth, students are in fact engaged in very creative activities to get to know what they know about stoichiometry concepts.

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CHAPTER ONE

SETTING THE SCENE FOR SI SUPPORT

1.1. Introduction

This study explores first year engineering students' engagement in chemistry Supplemental Instruction (SI) sessions at a tertiary institution in South Africa. SI is a student academic development and support programme targeting high risk courses. This research thus provides insight into an institutional project, chemistry SI that attempts to provide support to first year engineering students. Supplemental Instruction is therefore used as a vehicle to improve the quality of chemistry teaching and learning, and ultimately increase the overall throughput rates of engineering graduates.

In researching the role of Supplemental Instruction for first year engineering students', this study has implications for teaching and learning in higher education. The purpose of this study is to explore the synergy between what is taught in first year chemistry and the disciplinary knowledge that students are accessing. The study examines how first year Engineering students engage within SI sessions in constructing their understanding of chemistry concepts.

This study makes a contribution to knowledge by extending contextual, theoretical and methodological boundaries. The research site, at a tertiary institution in South Africa, provides the context in which chemistry Supplemental Instruction (SI) sessions were offered to first year engineering students in 2008. The study is therefore unique in the sense that it explores students' engagement within the context of stoichiometry in chemistry SI at a South African tertiary institution. Other South

African studies have looked at the effectiveness of SI in increasing pass rates or student learning (Huddle & Pillay, 1996; McCarthy & Smuts, 1997; Koch & Snyder, 1999; Vorster, 2000; Esterhuizen, De Beer & Baird, 2008), or the difficulties undergraduate students experience with stoichiometry (Onwu, 2002; Potgieter, 2005; Marais & Combrinck, 2009). These previous studies have worked from either a quantitative or qualitative analytical perspective, however, empirical data on how students' engage with stoichiometry in chemistry SI sessions is lacking. Current theory concerning the nature of student engagement for improving understandings particularly for disciplinary specialists and academic support staff, are an under-researched area in the field.

This study therefore extends theoretical boundaries by contributing towards filling the gap existing in Supplemental Instruction research concerning student engagement in first year chemistry in South Africa by building theory around SI engagement practices and how first year chemistry students construct meanings of stoichiometry concepts.

1.2. Rationale for the study

There are four issues that drive the rationale of this study and these are prompted by challenges experienced in chemistry teaching and learning; a baseline study which was conducted to establish how students like to learn chemistry; strategies of the Faculty of Science and Agriculture to improve the quality and throughput of graduates, and a personal interest in teaching and learning.

There are many challenges experienced in chemistry teaching today (Potgieter, 2009; Okanlawon, 2010). It is therefore important to understand the context of Supplemental Instruction at the University of KwaZulu-Natal (UKZN). UKZN was formed in 1 January 2004 as a result of the merger between the former universities of Durban-Westville and Natal (Durban and Pietermaritzburg). The new university brought together the rich histories of both former universities as well as increase in student population and diversity. The merger was part of a larger expansion and restructuring of the tertiary sector in South Africa, thereby challenging university lecturers with adjustment to larger number of students in classes: containing a wider range of student ability and motivation levels, under-resourcing from both a teaching and learning, and differing levels of student under-preparedness for tertiary education. At the University of KwaZulu-Natal, all engineering students who come into the faculty should have achieved at least 70% for both Physical Science and Mathematics at high school for their National Senior Certificate examination. It is proposed that under-preparedness in chemistry could stem from their meta-cognitive ability rather than their ability in the subject. According to Martin and Arendale (1993), many under-prepared university students do not know how to study because they have not yet developed the abstract reasoning skills that allow them to learn new ideas simply by reading a text or listening to a lecture. These skills are important to engineering education because engineering schools are supposedly preparing students who as professional engineers, will be required to work in self- directed ways through problem solving and collaborative team work. These issues have the potential to decline the overall first year standard of teaching and learning (Glaser & Poole, 1999).

One of the main problems experienced in teaching chemistry at UKZN is to successfully and effectively teach a large number of students with a wide range of abilities, backgrounds and academic interests. As suggested by Glaser & Poole (1999), confronted with such challenges, most lecturers fall back upon the method they are most familiar with, the lecture. They emphasise that the lecture mode is well-suited to students who are intrinsically motivated to learn and that this approach suffers greatly in the undergraduate curriculum, particularly in the first and second year courses where students choices are limited, enrolment is ‘required for the major’ and intrinsic motivation for learning is low. This is typical at UKZN, where the non-Chemical Engineering students do not grasp the significance of Chemistry in their degree programme; this may suggest why the Chemical Engineers perform significantly better than the non-Chemical Engineering students.

Besides the widely recognised limitations of lecturing to large number of students, there is also the lack of emphasis on higher-order thinking, problem-solving and active engagement in both teaching and learning (Glaser & Poole, 1999; Biggs, 2003 and Dalsgaard & Godsk, 2007). This study explores Engineering students' engagement in chemistry Supplemental Instruction at the University of KwaZulu-Natal in an attempt to better understand how the SI environment influences student engagement with chemistry content. Therefore factors influencing how students get to know and better understand stoichiometry concepts in the SI environment is the focus of this study, in an attempt to increase the throughput rates of engineering graduates.

Another challenge faced by chemistry teaching and learning emphasised by Lawson (2002), is that students often do not want to think for themselves, they just want to know the right answer. There is often a lack of necessary inquiry skills i.e. science process skills (Halkka, 2003, cited in Aksela, 2005). Most activities found in laboratory manuals require students to operate with lower-order thinking rather than with higher-order thinking skills (Domin, 1999). Students are often not allowed enough time for 'deep processing' of information due to time constraints and syllabus overload. Osborne (2003) also argues that many students lack interest in studying chemistry, which is regarded as a growing challenge. It is possible that this lack of interest noted by Osborne (2003), may be attributed to students not understanding the context in which they will use the material in the future.

A baseline study was conducted with first year engineering students' at UKZN in 2008 to establish the factors contributing to the success and failure of Engineering students at first year chemistry level (discussed more extensively in the background to this study). The results of the baseline study indicated that students preferred more interactive teaching and learning styles, which involved discussions, clarification of concepts and more opportunities to engage in problem solving exercises (Paideya, 2008). It was suggested that large class sizes and tiered venues made it almost impossible for group discussions and active learning practices.

The strategy proposed by the Faculty of Science and Agriculture at UKZN was to improve the quality and effectiveness of teaching and learning through improved practices, offering a diverse range of approaches to student learning thus providing a broader base of teaching and learning strategies (Zacharais, 2007). It was proposed that these strategies be informed by research into student difficulties (baseline study), and effectiveness of interventions (my current study), taking into consideration global trends and best practice which encompassed this research focus. Dalsgaard & Godsk (2007:41) support the argument that “it is important to provide students with a wide range of resources to meet their different needs and requirements”, which was also one of their findings during research conducted in “transforming traditional lectures into problem-based blended learning”.

Finally, the rationale for this study is also personal as I have been a chemistry educator for many years and I have had the experience of both teaching at secondary school and lecturing at university. However, my experiences have been similar, in that many students experience the chemistry curriculum as abstract, difficult to learn, and unrelated to the world in which they live (Pilot & Bulte, 2006; Osborne & Collins, 2001), and sometimes irrelevant to their educational needs. This has resulted in many students failing to proceed with chemistry modules.

These insights indicate a clear imperative that students must be actively involved in a process of learning which is valid for the subject being learnt. I have explored how engineering students engaged in Supplemental Instruction (SI), as a collaborative approach to teaching and learning. SI is a student academic assistance programme which is believed to increase student performance and retention (Martin & Arendale, 1993). This strategy will be explored for its effectiveness in engaging students with stoichiometry concepts through active learning strategies such as group and peer learning, discussion and explanation in chemistry SI learning spaces.

1.3. Background to the study

This study is driven by two projects: Throughput in Engineering Sciences (TIES) [1] and Project Sustain[2]. This study is part of a larger project referred to as the TIES

[1] The TIES Programme was established in 2008 with the aim of increasing the throughput rates of the first year engineering students and later mainstream science and mathematics students.

project, which was initiated and funded by the Department of Higher Education (DoHE), with particular focus on equity at the University of KwaZulu-Natal (UKZN). In the context of globalisation and the knowledge economy, higher education is seen as vital for national development in terms of turning out an appropriate number and mix of graduates of good quality, in terms of national needs (Scott, Yeld, Hendry, 2007). Also, modern society needs active, responsible citizens, with individuals who are able to assimilate information from multiple sources, determine their veracity, and make judgements (Wilson, 2000). This is the capacity to practise active citizenship as they employ higher-order thinking skills to build and test meaning. Therefore, attempting to improve students' abstract reasoning skills and throughput rates of Engineering and Science graduates is significant with respect to global and national needs. This notion of promoting development of and access to a socially responsible Science Education is in line with the objectives of Project Sustain, which is funding this PhD research project.

A baseline study (mentioned earlier) was embarked upon, which aimed to establish factors contributing to the success and failure of engineering students at first year chemistry level. This was deemed necessary in order to establish what the engineering students regarded as contributing to their success in chemistry teaching and learning, and also what factors were contributing to their failure in the chemistry course. As part of the research methodology, questionnaires were developed for first year chemistry lecturers and engineering students. In addition, four chemistry practical demonstrators and one tutor were interviewed. Four chemistry lectures, three practical demonstrations and two chemistry tutorial sessions were observed.

Questionnaires and interview schedules were designed focusing on student experiences of chemistry within first year Engineering. Thus, the purpose of the baseline study was to explore the first year engineering students' experiences of the chemistry curriculum at UKZN. The key research questions used to analyse the

[2] Project Sustain is funded by NUFU. The NUFU programme is a Norwegian programme of academic research and educational co-operation based on equal partnership between institutions in Norway and Southern hemisphere. The aim of NUFU is to support the development of sustainable capacity and competence for research particularly that based on higher education in developing countries, relevant to national development and poverty reduction and contributing to an enhanced academic collaboration in the South and between South and North.

baseline study dealt with how first year engineering students preferred to learn chemistry, challenges experienced by the engineering students in terms of teaching and learning within the chemistry module, and how the engineering students coped with these challenges.

As part of the DoHE project, one hundred and seventeen completed questionnaires from both chemical engineering and other engineering students, out of a total 453 engineering students, were analysed. A report was produced reflecting principled recommendations, which can be developed and thereafter implemented at UKZN. The following paragraphs outline significant insights which were gained from the baseline study, which guide the current research.

The lessons were largely lecturer-centred due to minimal discussion between students and lecturer. Interactions between lecturer and students were at most times based on clarification of concepts rather than discussion of concepts. The large number of students per class was noted, which contributed to the lack of effective interaction between students and lecturer.

Analysis of the questionnaires revealed that students preferred more interactive engagement or discussion around chemistry concepts. They claimed such interactive engagement was sometimes evident during chemistry practical sessions. The students further suggested those chemistry practical sessions were their only formal opportunity for collaborative engagement and were not always based on the dynamics of group work although students were required to work in groups in some instances. The other engineering students, i.e. besides the chemical engineers, could not see the significance of studying chemistry as they felt that it was irrelevant to their field of study; they therefore showed lack of motivation for the subject. This is interesting to note, since first year engineering chemistry is often far more relevant than the students thought (e.g. in materials of construction, semiconductors, etc.). Students found the tutorial sessions too short and that they did not get sufficient practice with chemistry problems; some of them viewed this session as merely to ‘come and get answers to the tutorial questions without much discussion’. This was due to the fact that chemistry tutorials were only allocated a forty-five minute session per week for the chemical engineering students and a forty-five minute session every alternative week for the other engineering students.

Further, analysis of the examination results of first year engineering students (part of the baseline study) from 2005-2008, indicated overall improvement in chemistry results, although on average, only 60% of these first year students complete their Engineering degree. Further, the chemistry results for engineering students show a diversity of student abilities with greater proportions of students on extreme ends of the ability spectrum. Upon analysis of the examination results, large discrepancies in terms of comparisons between overall pass rates and the quality of the pass rates can be seen (see Appendix 1). It is evident that the chemical engineering students perform significantly better than the other engineers. There could be many contributing factors such as the quality of examination and the fact that chemical engineering students have twice as many lectures per week as well as practical and tutorial sessions every week of the semester.

Guided by the above findings, it is clear that the students preferred more interactive, relevant and accessible methods of engaging with chemistry concepts. The results of the baseline study indicated that the first year engineering students viewed traditional university courses as content-based and lecture-based teaching, which to a large extent are not interactive and do not focus on the learning needs of individual students. It is argued that tertiary education should promote students' holistic development in cognitive, personal and affective domains, producing university graduates who are competent not only in their respective disciplines but also as independent lifelong learners (Jiang, 2004).

This research study therefore hinges on and is prompted by the results of the baseline study, which showed that the engineering students preferred more interactive methods of teaching and learning and that there is a need to improve the quality of engineering graduates. Supplemental Instruction (SI) was therefore introduced as a peer support programme for first year engineering students. SI is a student academic assistance programme which applies pedagogical strategies and aims at increasing academic performance and retention among students for high risk courses (Arendale, 1994). It is assumed that the primary focus of SI sessions is aiding student assimilation and understanding of course content by thinking, reasoning, analysing and problem solving (Phelps & Evans, 2006). Students in SI sessions work collaboratively to understand the course concepts, brainstorming ideas, engaging in discussions on how the concepts relate to each other and reflecting on the task with support from peer tutors also known as SI leaders (Martin & Arendale, 1993). According to McGuire (2006), these activities facilitate the students' greater conceptual understanding, and their success in problem solving tasks and examinations increases substantially.

It is therefore envisaged that this study on engineering student engagement in chemistry SI will inform future SI practice and strategies in improving students understanding of stoichiometry concepts within the TIES programme. This study also highlights the influence of SI in developing students' problem-solving skills, critical thinking skills and responsibility for learning which is aligned with the aims of Project Sustain.

1.4. Theoretical and Analytical Frameworks

Several connected theories have been used in this study to explore students' engagement in chemistry SI. Firstly, a social constructivist theoretical framework is used as SI has its foundation in interactive teaching and learning practices and is therefore based on social constructivist principles. The data collected are analysed using engagement theory which coheres with the findings in the data. Lastly, I make use of the phenomenon of social learning spaces which borrows from phenomenological theory to drive the thesis chapter which emphasises SI teaching and learning in social learning spaces. The three theoretical frameworks guided the study through data collection (social constructivism), data analysis (engagement theory) and thesis development (phenomenology).

1.4.1. Social Constructivism

SI has constructivism as its theoretical foundation and bears many similarities to problem based learning as they function on the premise of collaborative learning. Constructivism was greatly influenced by the later work of Jean Piaget and the socio-historical work of Lev Vygotsky (Fosnot, 1996). Biggs (2003) comments that what people construct from learning encounters depends on their motives and intentions, on what they know already, and on how they use their prior knowledge. He claims that meaning is therefore personal; learning is thus a way of interacting with the world. Thus, as we learn, our conceptions of phenomena change and we see the world differently. The acquisition of information in itself does not bring about change, but the way we structure that information and think with it does. Biggs (2003:21) therefore concludes that "education is about conceptual change, not just the acquisition of information". This notion articulates with the focus of this study concerning how student engagement in chemistry SI sessions may influence a better understanding of stoichiometry concepts.

Social constructivism shows that learning is not a purely internal process, nor is it a passive shaping of behaviours. Learning is constructed through interactions with and among other students. The social constructivist perspective provides authentic learning situations (Roth, 1995), situated cognition (Brown, Collins & Dugid, 1989) and cognitive apprenticeships (Hodson & Hodson, 1998b) that describe a way of knowing.

The notion of social constructivism has been given many interpretations. In one school of thought, according to Piaget, meaning making is a process of attaining 'equilibration' through thoughtful engagement in assimilation and accommodation; this is a process that occurs primarily at the individual cognitive level (Fosnot & Perry, 2005). Thus, we call his theory cognitive constructivism. Vygotsky, on the other hand, was more focused on the effects of social interaction, language, and culture on learning (Fosnot & Perry, 2005; Vrasidas, 2000). Vygotsky's theories stress the fundamental role of social interaction in the development of cognition (Vygotsky, 1978; Wertsch, 1985), as he believed strongly that community plays a central role in the process of "making meaning." (Vygotsky, 1978: 86) describes the “zone of proximal development” where learning takes place in discussions between students who have reached different levels in their individual learning and who can benefit from each other’s learning experience and knowledge with the guidance from a ‘more knowledgeable’ other. This theory is central to SI where students come up with solutions through common discussion and guidance from the SI leader being the ‘more knowledgeable’ other. Authors who adhere to this view and considered knowing and learning in terms of culture and practice are Lave & Wenger (1991); Brown, Collins & Duguid (1989); Lave (1988) and Cobb (2001).

In this study, SI sessions were presented as collaborative learning opportunities that involved group discussion and collaboration amongst peers, using ‘real world’ problems with respect to stoichiometry in some instances. According to Vygotsky’s zone of proximal development, the SI leader served as the more intelligible/knowledgeable other facilitating discussion among students who expressed different levels of understanding.

1.4.2. Engagement Theory

Engagement is understood in this study as two key components, viz.“ the amount of time and effort students spend on academic activities that lead to student success and secondly, the ways in which institutions allocate resources and organise learning opportunities and services to induce students to participate in and benefit from such activities” (Kuh, Kinze, Shuh and Whitt, 2005:9). With this definition in mind, engineering students’ engagement in chemistry SI is explored.

Kearsley and Shneiderman’s (1999) model on engagement theory is used to theorise the results of this study, which is based on students’ engagement in chemistry SI sessions, and the results thereof cohere with their model of engagement. “The fundamental idea underlying engagement theory is that students must be meaningfully engaged in learning activities through interaction with others and worthwhile tasks” (Kearsley & Shneiderman, 1999:1). They refer to engaged learning where all student activities involve active cognitive processes such as creating, problem-solving, reasoning, decision-making, and evaluation. In addition, students are intrinsically motivated to learn due to the meaningful nature of the learning environment and activities.

1.4.3. Phenomenon of Learning Space

The phenomenon of learning space refers to how learning happens in the SI learning spaces. In order to understand engineering students' experiences of engagement in the social learning spaces created during SI sessions, a phenomenological approach to space is used which theorises the phenomenon of learning. Phenomenology has its own ways of looking at space. Merleau-Ponty (1945), states that there is an objective space and an existential space. The objective space is the space dealt with by science. Existential space is lived, phenomenal and virtual space. This kind of space has a lot to do with emotions, feelings and lives in the mind of a person. This study reveals that students believe that motivation plays a fundamental role in inspiring them to learn which is based on emotions and feelings. According to Oude Groeniger and van Veldhuizen[3] (undated:3), learning space is rich and complex, and ordered with reference to human intentions and experience for we are immersed yet extended in space through our actions and perceptions. It is not obscure or abstract, but part of everyday experience. Through phenomenology we can gain insight into the connection between the life-world and the world of science (Gould & Olsson, 1982).

The aim of the phenomenological approach is to describe and not to explain Diemers (2000), model on Phenomenological space is thus used to describe the SI social learning in relation to other space such as the geographic space, students' cognitive space and the common interactive space. This however, does not mean the dismissal of our own experience. It means stepping back and examining it with self-awareness. This suspension of the researchers' belief is known as epoché in phenomenology.

[3]http://socgeo.ruhosting.nl/html/files/geoapp/Werkstukken/Phenomenological Space.pdf

The above theoretical and analytical frameworks guide the study in exploring how Engineering students engage in chemistry SI sessions. Given the above discussion, specific research questions were developed.

1.5. Key research questions

It is envisaged that the chemistry teaching and learning engagement within SI is made more meaningful, relevant and engaging for students with a wide range of abilities for a wide range of academic majors and interests. With this in mind, the following critical questions were derived:

1. How does the chemistry Supplemental Instruction (SI) learning environment influence student engagement?
2. How do the first year Engineering students engage in the chemistry SI environment?
3. Why do these Engineering students engage in the way that they do?

The above research questions were developed to create insights with respect to firstly, how the SI leader created a chemistry SI environment that influenced student engagement. This question tries to elicit information about the SI structure. Secondly, it addresses how students engage in learning in the SI environment – this question is designed to find out if there is any influence of SI structure that improves their learning, and to uncover how students learn chemistry, with particular reference to developing understanding of stoichiometry through SI. The third question attempts to theorise why the students engaged in the way that they did.

1.6. The significance of this study

This research is significant in that it aims to improve the quality of chemistry teaching and learning by informing the effectiveness of the SI teaching and learning intervention within the TIES project. According to a report by the Council of Higher

Education in November 2004, the challenges facing South African higher education are described as two fold. Firstly, there is a need to achieve social equity in order to overcome the legacy of apartheid and secondly, there is the imperative to engage with a competitive global market for science and engineering human resources (Scott et.al. 2007). These are some of the challenges recognised by the TIES project, which aims to increase the number of graduates in engineering and science courses addressing the shortage of such skills in South Africa.

This research is aimed at informing and improving educational practices, in engineering and science, using a design research methodology. The students' engagement in chemistry SI teaching and learning is used to better understand the SI leader's needs and students' thoughts and actions during their learning. The better we understand how, when, and why to implement innovations in chemistry instruction, the more effectively are learning and teaching environments created. This understanding will advance instructional design knowledge by understanding real-world demands placed on designs and design adopters, and will increase our capacity for educational innovation in chemistry through design research (Design-based Research collective, 2003).

Adopting an interactive approach to teaching and learning has indicated positive outcomes in reviews of small group activities in terms of higher achievement, increased positive attitudes towards the subject area studied, higher self-esteem, greater persistence and retention, and enhanced conceptual development across content areas in a wide range of educational settings (Cohen, 1994; Johnson & Johnson, 1994). Further, the Nelson Mandela Metropolitan University (NMMU) Training Manual (2008) emphasises the benefits of active learning through Supplemental Instruction in terms of:

- Developing students' acceptance of peers and their opinions[4].
- Better understanding of course material[5].
- More cognitive processing of material[6].

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[4] Voster (2000). The Process of teaching and learning in Supplemental Instruction groups
[5] Webster & Hooper (1998). Supplemental Instruction for introductory chemistry courses

- Exposure to new ideas and more ways of thinking about things[7].
- Better identification of student's misconceptions and gaps in understanding of materials[8].
- Increased retention[9].
- Increased self-esteem of participants[10].

It is hoped that the findings of this study will be able to inform effective and innovative practices with respect to student engagement in SI sessions that will improve the quality of students' performance in chemistry both nationally and internationally. Literature on SI has mainly been concerned with foregrounding the benefits of SI by establishing a causal effect between SI attendance and pass rates (Bowles, McCoy & Bates 2008; Gardner, Moll & Pyke 2005; Mara & Litzinger 2002), or the SI leader's role in SI (Mannikko-Barbutiu 2004; Lockie & Van Lanen 2008). The findings will also contribute to a body of existing knowledge on students' experiences of innovative practices in South African studies, as noted on pages one and two of this study and in international studies (Webster, 1998; McGuire, 2006) to inform the quality of students' learning experiences in first year chemistry SI.

1.7. Overview and structure of the thesis

Chapter One of this thesis provides the background to and rationale that drives this study. It provides insights into an institutional project that attempts to provide support to first year engineering students through the introduction of Supplemental Instruction (SI), as a vehicle to improve the quality of chemistry teaching and learning. The impact of SI was intentionally excluded to allow greater focus on the

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[6] McGuire (2006). The Impact of Supplemental Instruction on teaching students how to learn.
[7] Capstick & Fleming (2002). Peer assisted learning in a undergraduate hospitality course
[8] Rath, Peterfreund, Xenos, Baylis & Carnal (2007), SI in Biology 1: enhancing the performance and retention of underrepresented minority students.
[9] Bowles, McCoy & Bates (2008), The effect of supplemental instruction on timely graduation.
[10] Malm, Bryngfors & Morner (2011), Supplemental Instruction for improving first year results in engineering studies.

phenomenon of learning within the context of SI in which interactions are explored and examined.

Chapter Two consists of two parts: Part One focuses on SI as context and concept in this study and Part Two reviews the literature surrounding chemistry learning in higher education with particular focus on first year Engineering students, supplemental instruction and stoichiometry. SI as concept and context are important framing measures in this thesis especially in relation to UKZN. The literature suggests that research around stoichiometry has been largely about the levels of difficulties experienced and these difficulties appear in different ways in terms of classroom interaction, institutional learning, conceptual analysis, etc.

Chapter Three focuses on the theoretical framings of social constructivism, conceptual development and meta-cognitivism. Social constructivism is theorised with respect to Engineering students' engagement; this is followed by a discussion on how students achieve conceptual change and finally, how students become aware of their cognitive processes (meta-cognition). In other words, it examines how students' social engagement leads to their conceptual development and knowing of stoichiometry concepts.

Chapter Four reveals how Design research methodology is used to understand the influence of the SI environment on first year engineering students' engagement in chemistry SI, by theorising the research approach and design, outlining the data production plan and elaborating the layered data analysis techniques used in the study. A design research study approach is argued for with respect to an interpretive paradigm. What constitutes design research is explained; the inherent features of design research and how design research is played out in this study are examined. The role of Supplemental Instruction and its contribution to this research environment is discussed. Lastly, the data production methods employed by this research are presented and insight into data analysis is revealed. The study pushes methodological boundaries in that rather than locating the study paradigmatically and aligning it with a particular paradigm, it is located within methodologically appropriate strategies for data production. Examining what is methodologically appropriate at each phase of the data production process allowed for the flexibility to pursue an iterative process of data collection, producing appropriate data for the study. This innovative approach to methodological paradigms, the iterative process, as well as the data collection strategies employed in this study, will be theorised in the methodology chapter as well as in the final chapter of this thesis. This study, however, does not report on iterative cycles of all three phases of the design research, but is rather confined to the implementation and reflective phases so as to focus on students' engagement in chemistry SI.

Chapter Five provides the descriptive or interpretative framework within which the social constructivist layers of analysis take place. The analysis spans Chapters Five and Six, which are arranged thematically with each chapter representing patterns emerging from the data. Chapter Five analyses the first critical question of the study. Focus group interviews, SI leaders Reflective Journal entries and video data revealed the following themes with respect to how the SI environment influenced student engagement, viz. pedagogically and socially.

Chapter Six answers the second critical question. This chapter makes use of qualitative data from the focus group interviews, individual interviews and video recordings of SI sessions, which have been inserted selectively to determine how students engage in the chemistry SI sessions. Three broad themes were derived from the data that described students' engagement in chemistry SI viz. experientially, social learning engagement and strategically

Chapter Seven provides a descriptive thematic analysis of the third critical question of the study. This chapter theorises why students engage with stoichiometry concepts in chemistry SI in the way that they do, borrowing from the ideas proposed in Kearsley & Shneiderman's (1999) model on engagement theory which is used to drive the emerging thesis. Engagement theory is used as it focuses on self-directed learning, problem solving and successful collaboration and teamwork, which co-inside with the insights of this study.

Chapter Eight is the final thesis chapter, which theorises the notion of 'SI social learning space' emerging from the analysis chapters, and discusses its implications for the practice of Supplemental Instruction sessions. This chapter also concludes with new understandings of the teaching and learning of chemistry in SI sessions and presents a theoretical model for the design of chemistry learning. Finally, this chapter outlines the implications of this model for Supplemental Instruction work generally, and for higher education broadly, concluding with a reflection on the methodological implications for the study.

1.8. Conclusion

This chapter discussed the rationale, background of the study, limitations, theoretical and analytical frameworks of this study. The next chapter reveals SI as context and concept and unpacks relevant literature in support of first year students' learning and engagement in chemistry and higher education.

CHAPTER TWO

SUPPLEMENTAL INSTRUCTION AS CONTEXT AND CONCEPT UNPACKED: AN OVERVIEW OF LITERATURE

2.1. Introduction

In this chapter I argue for the framing of SI as *context* with respect to its role within an institutional *context*, the *context* of engineering and the pedagogical *context* of chemistry. In addition, SI as *concept* is viewed with respect to collaborative learning as the fundamental conceptual framework for SI, by analysing relevant literature. SI as *concept* and *context* are important framing measures in this thesis in terms of understanding students' engagement in chemistry SI sessions. This chapter is divided into two parts: section (a) will provide an overview of SI as *context* and *concept,* and section (b) reviews literature relating to student learning – specifically learning stoichiometry in chemistry and science in higher education, with particular reference to first year engineering students.

2.2. Section A: SI as *Context* and *Concept*

A *context* is defined as the teaching and learning environment (in this case the SI environment), which influences how students learn (Trigwell and Prosser, 1991). This chapter begins with a review of SI in the South African context. An overview of SI as a support structure is discussed, highlighting key features of the SI programme. The fundamental underpinnings of SI as a concept are then discussed and its link with collaborative learning practices examined. A brief overview of the assumptions and challenges of learning that accompany a collaborative model of learning are then explored in relation to the SI model.

2.2.1. SI in the South African Research Context

The role of Supplemental Instruction in the South African *context* is discussed with respect to its contribution to the institutional context of UKZN and the Faculty of Engineering, and the pedagogical *context* of first year engineering chemistry. It is argued that first year engineering students' under-preparedness for the university context resulted in SI being introduced as a transitional support programme at UKZN. In contrast to chemistry lectures, SI is based on collaborative learning principles which are assumed to develop students' conceptual understanding of chemistry principles. The SI leaders' role in facilitating the learning process in a collaborative learning environment is outlined as being significant in the learning process.

2.2.1.1. SI in the Institutional and Engineering Context

The Engineering faculty at the University in KwaZulu-Natal has a rich diversity of students ranging from differing academic abilities and secondary school experiences. It remains a reality in South Africa that past imbalances in the education system continue to perpetuate poorly resourced schools and inadequately skilled teachers, particularly in the fields of mathematics and science, resulting in many under-prepared university students. Martin and Arendale (1993) claim that these students experience difficulties at university as they do not know how to study because they have not yet developed the abstract reasoning skills that allow them to learn new ideas simply by reading a text or listening to a lecture. This is important to engineering education because engineering schools are supposedly preparing students who as professional engineers, will be required to work in self-directed ways through problem solving and collaborative team work. To exacerbate the disadvantaged position, many of these students have English (the medium of instruction) as second or third language.

"The cumulative effect of these factors creates a situation where students enter university with an inadequate knowledge of either the basic symbolic language of chemistry, or the fundamental principles which underpin the study of chemistry" (Marais and Combrinck, 2009: 88). The Faculty of Science and Agriculture at the university has recognised that students in their first year of study have particular learning needs as a result of their differing backgrounds, previous learning experiences and their often under-developed learning skills[11]. In 2008, Supplemental Instruction (SI) was introduced as a transitional support for the first year engineering students. SI is a student academic assistance programme which applies strategies and aims at increasing academic performance and retention amongst students for high risk courses.

2.2.1.2. SI in the Teaching Context

Chemistry courses are taught in a large lecture format in conjunction with laboratory sessions. In these settings, topics are presented in lectures and reinforced through exam and tutorial sessions. The laboratory sessions summarise key lecture topics through routine chemistry experiments while the tutorial sessions which are 45 minutes long, either held once a week or every alternate week and due to time constraints, deal mainly with algorithmic style problems. Studies have illustrated that this school of thought, although properly instructing students on how to solve problems algorithmically, does not empower them with conceptual chemistry knowledge (BouJaoude & Barakat, 2000; Furio, Azcona, Guisasola, 2002; Fach, Boer & Parchmann 2007; Okanlawon, 2010). The traditional lecture, laboratory sessions and tutorials (owing to size and algorithmic approach) do not provide sufficient interaction or feedback avenues to ensure conceptual mastery of chemistry concepts and consequent reduction of student attrition in the later years of study (Webster & Hooper, 1998). It is also possible that high school teaching methods which are currently being used, are in opposition to the traditional lecture approach.

The lack of conceptual understanding of chemistry principles mentioned above has been vastly researched, yielding positive results when direct team learning methods were introduced into chemistry lectures (De Jesus, 1995; Phelps, 1996; Kogut, 1996 cited in Webster et al., 1998). The approach at UKZN was to utilise team learning methods viz. Supplemental Instruction, so as not to disrupt the lecture format. An SI

[11] This is anecdotal.

session is neither a lecture nor a lesson in the traditional sense of the word but rather a formal learning space where students discuss the subject matter (in this case chemistry) on a voluntary basis and out of their own interest. These sessions are usually held for 45 minutes twice a week. The SI sessions integrate facilitative measures to encourage an atmosphere that emphasises that “no question is a dumb question” (Webster & Hooper, 1998), thereby encouraging the students to ask the dreaded question “why”. The learning spaces designated for SI sessions are flat rooms with approximately 5 round tables seating 8 students to enable communal arrangements. The limited seating per room is deliberately designed to facilitate small group discussions. This physical environment has been specifically created to encourage a collaborative learning space for SI sessions.

These SI sessions are conducted by third year or post-graduate students who are referred to as SI leaders. SI leaders are recruited by the SI supervisor and faculty members based on their interpersonal skills and course competency. SI leaders are not tutors; their role is not to introduce new content or “re-teach” lecture material as mentioned earlier (Dawson, Lockyer & Ferry, 2007). They are responsible for facilitating the discussions and preparing activities for their sessions.

2.2.1.3. Role of the SI leader

SI leaders were allocated two days of training before they actually started with SI sessions. SI leaders are trained with respect to SI principles and facilitation techniques prior to commencement of SI sessions. The focus of the training is to introduce the basic ideas of SI to the participants and give them tools for their role as an SI leader.

The SI leader assumes the following roles in the SI environment (Mannikko-Barbutiu & Sjogrund, 2004).

- Pedagogical role where the SI leader uses questions, prompts and probes for student responses that focus discussions on critical concepts, principles and skills. This role may include a number of tasks such as: opening the discussions, focusing on relevant content and issues, intervening in order to promote interest and productive conversation, guiding and maintaining students' involvement in discussions, and summarising debates. Additionally, this role may encompass directing and focusing discussions on vital points, synthesising points made by the participants and providing summaries of discussions.

- Social roles involve the creation of friendly and comfortable social environments in which students feel that learning is possible. In this context, SI leaders are responsible for: guaranteeing opportunities for participants to introduce themselves; identifying and dealing with students who are reticent and sometimes reluctant to participate; ensuring that appropriate communication takes place; taking into consideration cultural and ethnic backgrounds by minimising humoristic, offensive and disruptive behaviour and promoting interactivity between students.

- Organisational roles involve setting learning objectives; establishing agendas for the learning activities; timetabling learning activities and tasks; clarifying procedural rules and decision-making norms. These roles also include: encouraging participants to be clear, responding to the participants' contributions, being patient, following the flow of the conversation and encouraging comments, synchronising, handling overload of information, encouraging participation, and ending the sessions.

- Supportive roles, this role includes supporting the students in becoming competent and comfortable themselves by providing guidance such as: offering study guides, directions and feedback on problems, ensuring and encouraging peer learning.

SI leaders attempt to establish a collaborative learning environment by having students work together to complete and practise questions/problems based on chemistry content covered in their preceding lecture. The SI supervisor serves the role of mentor, and his/her primary aims are the support of SI leaders and for quality assurance of the SI program. This design reflects literature findings that tangibly demonstrate that effort is valued to help motivate students (Ames & Ames, 1990), reduce social comparison (Skinner & Belmont, 1993) and promote students' adoption of mastery goals (Wolters, 2004).

2.3. Overview of Supplemental Instruction as a support structure

As mentioned previously, the Supplemental Instruction approach is an undergraduate teaching assistant model developed by Deanna Martin at the University of Missouri-Kansas City in 1973 with a goal of helping students achieve mastery of course content while they develop and integrate effective learning and study skill strategies[12]. Martin & Arendale (1993) described SI as a student academic assistance program that increased academic performance and retention through the use of collaborative learning strategies. Martin & Arendale (1993) further claimed that this approach focuses on "at risk classes," rather than "at risk students" to avoid the remedial stigma associated with traditional academic assistance programmes.

Undergraduates who have done well in their classes are invited to become "SI leaders." These students are paid to attend the class, and to convene Supplemental Instruction sessions at least two times a week at hours convenient to students in the class. (Blanc, DeBuhr and Martin, 1983). SI leaders go through a two day training programme followed by continuous training, periodic monitoring and support by the SI supervisor as the semester progresses. SI training emphasises effective group learning techniques and ways to integrate various study skills (lecture note taking, textbook reading, memory enhancement and time management). The initial training involves "mock" SI sessions that simulate ineffective or unproductive SI sessions (ranging from uncooperative students to students wanting a large amount of individual attention from the SI leader). Thus the initial training allows the SI leaders to identify a group dynamic problem, adapt to each situation and incorporate techniques necessary to create a favourable group learning situation.

[12] History of SI accessed from www.SI.net

After each of the SI leaders monitored session, the SI supervisor offers constructive criticism on ways to keep the learning process collaborative, informative and fun while combining study skills. An additional portion of the semester long training process involves weekly or biweekly meetings between all participating SI leaders to discuss common session problems and to brainstorm possible future session activities that will enhance the learning process. Lastly, the SI leaders are required to attend course lectures, in this case first year engineering chemistry lectures, to keep abreast with content covered in lectures. The course lecturer is aware of the SI leaders' presence at lectures and allows them to make periodic announcements concerning SI session meeting times and the benefits of SI participation. The SI leader serves as a feedback mechanism for the course lecturer through discussion with lecturers about concerns and difficulties students may be experiencing with course material.

SI sessions are usually held within 48 hours of the lecture and therefore represent an immediate recall of course information. Questions that arise during this process are answered by the groups of SI participants and not the SI leader who mostly plays a facilitation and support role. This method forces students to speak and learn chemistry vocabulary and consequently reinforces pertinent information (Webster & Hooper, 1998). The problem based method employed during SI sessions involves small group discussions and reflection followed by one member of the group being responsible for writing and explaining the 'answer' on the blackboard, while the rest of the group justifies its validity through discussion. Session activities vary throughout the semester, according to SI attendee and leaders' needs. This model of SI has been adopted by UKZN and adapted to the South African context by NMMU's national office which coordinates SI in the country.

2.4. SI as *Concept*: Fundamental underpinnings of Supplemental Instruction

SI is regarded as an important mechanism for introducing students to the learning process, engaging them in collaborative learning activities and providing a collegial environment that increases motivation to engage in learning (McGuire, 2006).

Supplemental Instruction therefore provides opportunities for students to build new knowledge in collaboration with peers, in learning activities such as group discussions and problem solving. Collaborative learning makes a strong contribution towards students becoming active learners rather than passive recipients of information (Tinto, 1999). Dawson, Lockyer & Ferry (2007) emphasise that SI builds upon the work of social constructivists such as Vygotsky (1978), where learning in SI occurs as students collaborate on activities within their individual Zones of Proximal Development, and with the group's assistance are able to do things they could not do independently.

Light (1990) indicates that in every comparison of how much students learn when they work in small groups or when they work alone, small groups showed the best outcomes. Such collaborative experiences improved both the cognitive and affective domains of students (Sandberg, 1990). "The students peer group is the single most potent source of influence on growth and development during the undergraduate years" (Astin, 1993: 398). Studies in meta-cognition also suggest that students must assume the role of "self-regulated learners" to both persist in college and master difficult academic subject matter (Weinstein and Stone, in press). Given that collaborative learning is a feature of SI, the discussion that follows argues for SI as a collaborative learning endeavor.

2.4.1. SI as a Collaborative learning endeavour

According to Smith & MacGregor (1992), collaborative learning represents a significant shift away from the typical teacher centred or lecture-centred milieu in college classrooms. In collaborative classrooms, the lecturing/ listening/note-taking process may not disappear entirely, but it lives alongside other processes that are based in students' discussion and active work with the course material. Teachers who use collaborative learning approaches tend to think of themselves less as expert transmitters of knowledge to students, and more as expert designers of intellectual experiences for students as coaches or mid-wives of a more emergent learning process.

2.4.1.1. Assumptions about Learning in a collaborative environment

There are a number of assumptions that underpin collaborative learning. Dixon, Dixon & Axmann (2008), highlight the following assumptions:

- Knowledge is created through interaction and not simply transferred.
- Learning needs to be student centred.
- The educator's role is that of facilitator, developer and provider of the learning space.

Smith & MacGregor (1992), further expand these assumptions about learning to include:

- Learning as an active, constructive process in which students learn new information, ideas or skills by working actively in purposeful ways. Students' need to integrate this new material with what they already know or use it to reorganise what they thought they knew. In collaborative learning situations, students are not simply taking in new information or ideas. They are creating something new with the information and ideas, leading to the intellectual processing of constructing meaning or creating some new idea which is crucial to learning.

- Learning depends on rich contexts; recent research suggests learning is fundamentally influenced by the context and activity in which it is embedded (Brown, Collins and Duguid, 1989). Collaborative learning activities immerse students in challenging tasks or questions. Rather than beginning with facts and ideas and then moving to applications, collaborative learning activities frequently begin with problems, for which students must marshal pertinent facts and ideas. Instead of being distant observers of questions and answers, or problems and solutions, students become immediate practitioners. Rich contexts challenge students to practise and develop higher order reasoning and problem solving skills.

- Students are diverse and therefore bring multiple perspectives to the classroom-diverse backgrounds, learning styles, experiences, and aspirations. When students work together on their learning in class, a direct and immediate sense of how they are learning, what experiences and ideas they bring to their work, is derived. The diverse perspectives that emerge in collaborative activities are found to be clarifying and illuminating for students.

- Learning is inherently social as Golub (1988) points out and the main feature of collaborative learning is that it allows for student talk where students are supposed to talk with each other and in this talking much of the learning occurs. Collaborative learning produces intellectual synergy of many minds coming to bear on a problem, and the social stimulation of mutual engagement in a common endeavour. Mutual exploration, meaning-making, and feedback often lead to better understanding on the part of students, and to the creation of new understandings for all.

From the discussion above, it can therefore be argued that SI as a collaborative learning endeavour assumes that learning is an active construction of knowledge, learning is student-centred , facilitated, it is dependent on a rich context which immerses students in challenging tasks, creates diverse perspectives that are clarifying and illuminating for students and is inherently social in nature.

2.4.1.2. Educational Goals of collaborative learning

Collaborative learning promotes a larger educational agenda, one that encompasses several intertwined rationales, as indicated by Smith & MacGregor (1992):

- Involvement in learning, involvement with other students, and involvement with faculty are factors that make an overwhelming difference in student retention and success in college. By its very nature, collaborative learning is both socially and intellectually involving. It invites students to build closer connections to other students, their faculty, their courses and their learning (Kuh, 1991).

- In collaborative endeavours, cultivation of teamwork, community building, and leadership skills are legitimate and valuable classroom goals, not just extracurricular ones.

In essence, collaborative learning tasks embarked upon during SI sessions have the potential to develop the engineering students socially and intellectually cultivating a team spirit and leadership skills which are valuable goals for engineering students to compete on the global market. Furthermore, the Engineering Council of South Africa (ECSA) emphasises team work, lifelong learning and leadership skills as inherent features of engineers.

2.4.1.3. Collaborative Learning: Challenges and Opportunities

Creating a collaborative classroom can be a wonderfully rewarding opportunity (Smith & MacGregor, 1992) but it is also full of challenges and dilemmas as depicted by SI leader training and retraining which played a significant role in enabling SI leaders to move away from a dominating role in the SI environment to facilitate engagement of students in group activities.

Other studies referred to by Smith & MacGregor (1992), have indicated that designing group work requires a demanding yet important rethinking of syllabus, in terms of course content coverage and time allocation. In contrast, SI provides opportunities for students to build new knowledge in collaboration with peers, in learning activities such as group discussions and problem solving, where the focus is on process rather than content coverage and has different challenges. SI sessions should provide opportunities to cover all problem areas highlighted by the students. As such, collaborative settings put front and centre the tension between the **process** of student learning and **content** coverage.

Collaborative learning goes to the roots of long-held assumptions about teaching and learning. Classroom roles change: both teachers (in this case the SI leaders) and students take on more complex roles and responsibilities (Finkel &Monk, 1983; MacGregor, 1990). The classroom becomes more an interdependent community with all the joys and tensions and difficulties that attend all communities. This degree of involvement often questions and reshapes assumed power relationships between teachers (SI leaders) and students, (and between students and students), a process that at first can be confusing and disorienting (Romer & Whipple, 1990).

Smith & MacGregor (1992) state that challenges to collaborative learning at the classroom level can be compounded by the traditional structures and culture of the institution, which continue to perpetuate the teacher-centred, transmission of information model of teaching and learning. The political economy of the institution is set up to front load the curriculum with large lower division classes in rooms immutably arranged for lectures, usually in classes limited to fifty-minute “hours.” This is, however, not particularly the case for SI sessions held with the engineering students on this campus of UKZN but is evident on other UKZN campuses, where lecture venues used for collaborative learning tasks, pose grave challenges with respect to collaborative learning endeavours. Time constraints are definitely a factor in terms of engaging students collaboratively in SI and achieving the agenda for the session. Student-student interaction; careful examination of ideas; the hearing-out of multiple perspectives, the development of an intellectual community - all these are hard to accomplish under normal circumstances which encourage collaboration amongst students. These constraints make achieving collaborative endeavours more challenging.

Stemming from the traditional structure and culture of the institution lies the challenge of actually promoting collaboration amongst students. Due to their diverse backgrounds, students tend to gravitate towards other students from the same secondary institution, the same area of dwelling or those with the same first language. Creating collaborative mixed ability groups to promote peer learning can therefore also present a challenge. The SI leaders’ role in creating collaborative groups that encourage trust, participation and mixed ability, can be quite complex and demanding.

The discussion above reveals that collaborative classrooms stimulate both students and teachers (SI leaders). "In the most authentic of ways, the collaborative learning process models what it means to question, learn and understand in concert with others. Learning collaboratively demands responsibility, persistence and sensitivity, but the result can be a community of learners in which everyone is welcome to join, participate and grow" (Smith & MacGregor, 1992: 9).

2.4.1.4. Other SI Challenges

According to Arendale (1994), it is known that conducting SI in content areas where pre-requisite skills are a key variable, such as chemistry, can be more challenging. This is so if students do not remember mathematical knowledge (ratio and proportion) and cannot conceptualise the abstract nature of some chemistry concepts, such as stoichiometry in chemistry. Students will therefore have a difficult time in chemistry SI. He suggests that SI can be effective in these areas provided that:

- SI leaders invest more time in planning SI sessions, and
- SI sessions are longer than fifty minutes,

to cover additional material and provide additional time for students to practise with and master the course material and study strategies.

A further challenge to the SI model as indicated by Arendale (1994) could be with courses that are problem-based and involve practice for mastery. In those circumstances, SI sessions need to be more frequent and sometimes longer. For example, the course might require sufficient SI sessions to allow for the review of various types of problems or extended sessions to allow time for modelling and practice so that students become proficient problem solvers.

Also, as SI is purely voluntary and students are known to display poor time management skills, it has been found that in most instances, the more organised students are attending and are thus excelling in the course.

The conceptual framing of SI with respect to meta-cognition and conceptual development will be discussed in sections 4 and 3 respectively of Chapter Three, which follows as part of the theoretical framing that guides this study.

2.5. Conclusion

This chapter discusses SI in the South African research context, the pedagogical context of stoichiometry learning and the role of the SI leader in developing the SI context. SI as a concept is discussed with respect to the fundamental underpinnings of SI, viz. collaborative learning. Lastly the challenges and opportunities of collaborative learning are discussed. It is evident from the above discussion that chemistry and in particular stoichiometry (which provides the research context for this study), is based on abstract reasoning skills which could pose additional challenges to the SI leader. It would therefore be interesting to note how the SI leader manages such challenges.

The next section of this chapter looks at the literature in support of first year students' learning and engagement in chemistry and higher education.

Section B: Literature Review

This section reviews literature about learning specifically learning chemistry and science in higher education, with particular reference to first year engineering students. The links between teaching and learning sometimes appear weak, yet the teaching approaches are intended to enhance and improve the way students learn (Brown, 2004). An overview of the nature of chemistry learning with special emphasis on meaningful learning approaches, and how students get to know chemistry concepts with specific reference to the use of mental models in developing an understanding of chemistry concepts is discussed and students' learning of stoichiometry concepts is highlighted, reflecting students' difficulties in learning stoichiometry concepts. The close affinity of learning and understanding is evident in the various models of learning that are described in section 2.6.2. Lastly, engineering students' engagement in higher education is looked at with particular reference to improving first year students' under-preparedness for higher education and the challenges of globalisation of the economy.

2.6. The Nature of Chemistry learning

In this section, referred to as nature of learning, three issues are discussed. The first aspect will look at the review of the approaches to meaningful learning. This section examines the way students learn chemistry, in particular stoichiometry, focusing on learning styles and learning strategies. This allows the researcher to interpret the learning process better in understanding how engineering students engage with stoichiometry concepts in SI sessions and how SI influences student learning. It is argued that chemists use mental models to develop a better understanding of abstract and complex chemistry phenomena. Several models are central to chemistry learning which will be explained. Thereafter, chemistry learning will be examined with specific reference to the difficulties in respect to students' learning in chemistry.

2.6.1. Approaches to Meaningful Learning

Ausubel (1968: 12) reminds us that "teaching and learning are not coextensive, for teaching is only one of the conditions that may influence learning". In attempts to describe the varying depth of the learning process, the following terminology is commonly encountered: shallow learning (Atherton, 2001), quick learning (Schommer, 1990), rote learning (Battino, 1992), algorithmic style learning (Smith & Mason, 1997), instrumental understanding (Skemp, 1976), passive learning (Yager, 1991) and surface approach to studying (Ramsden, 1992). These approaches are characterised by a lack of conceptual understanding or cognitive effort. In contrast to this are meaningful learning (Ausubel, 1968), intentional learning, relational understanding (Skemp, 1976), deep approach to study (Ramsden, 1992), strategic learning (Jones, 1997) and active learning (Duit & Treagust, 1998). The later approaches are characterised by student-centred learning with greater conceptual understanding resulting in higher order reasoning and thinking skills and deep processing of information and cognitive strategies of high elaboration (Hennessey, 2003). Learning is described in terms of the level of understanding that is achieved. Hennessey (2003: 118) describes the term 'high elaboration' to mean "deep processing of information, elaborate cognitive strategies of connecting and comparing existing conceptions with new information and significant meta-cognitive reflection about what they were thinking and why". These descriptions of learning are useful and all educators have aspirations to achieve Hennessey's high elaboration level of understanding for their students; however, these descriptors in fact tell us very little about how students learn.

2.6.2. How students learn chemistry

Sirhan (2007) suggests that chemistry is one of the most important branches of science; it enables learners to understand what happens around them. Because chemistry topics are generally related to or based on the structure of matter, chemistry proves a difficult subject for many students. Chemistry curricula commonly incorporate many abstract concepts, which are central to further learning in both chemistry and other sciences (Taber, 2002). These abstract concepts are important because further chemistry/science concepts or theories cannot be easily understood if these underpinning concepts are not sufficiently grasped by the student (Zoller, 1990; Nakhleh, 1992; Ayas & Demirbaş, 1997; Coll & Treagust, 2001a; Nicoll, 2001). The abstract nature of chemistry along with other content learning difficulties (e.g. the mathematical nature of much chemistry) means that chemistry classes require a higher-level skill set (Fensham, 1988; Zoller, 1990; Taber, 2002).

Chemistry is therefore often regarded as a difficult subject, an observation that sometimes repels students from continuing with studies in chemistry. One of the essential characteristics of chemistry is the constant interplay between the macroscopic and microscopic levels of thought, and it is this aspect of chemistry learning that represents a significant challenge to novices (Bradley & Brand, 1985). In his early study, Johnstone (1974) reported that the problem areas in the subject, from the students' point of view, persisted well into university education, the most difficult topics being the mole, chemical formulae and equations (all of which fall under the topic of stoichiometry) and in organic chemistry, condensations and hydrolysis.

Chemistry, by its very nature, is highly conceptual. While much can be acquired by rote learning (this often being reflected by efficient recall in examination questions), real understanding demands the bringing together of conceptual understandings in a meaningful way. Thus, while students show some evidence of learning and understanding in examination papers, researchers find evidence of misconceptions, rote learning, and of certain areas of basic chemistry which are still not understood even at degree-level (Johnstone, 1984; Bodner, 1991): What is taught is not always what is learned.

Sirhan (2007) found four areas of difficulty with respect to student learning in chemistry viz. curriculum content, overload of students’ working memory space, language and communication and motivation. In terms of curriculum and content, it was established that much school chemistry, taught before 1960, laid great emphasis on descriptive chemistry, memorisation being an important skill for examination success. The sub-microscopic interpretation and symbolic representation were left until later (see Figure 2.1). Today, the descriptive is taught alongside both the 'micro' and 'representational'.

Johnstone (1982) has argued that the student cannot cope with all three levels being taught at once. Gabel (1999) supports this argument that there is a danger that chemistry depends too much on the representational, with inadequate emphasis on the descriptive

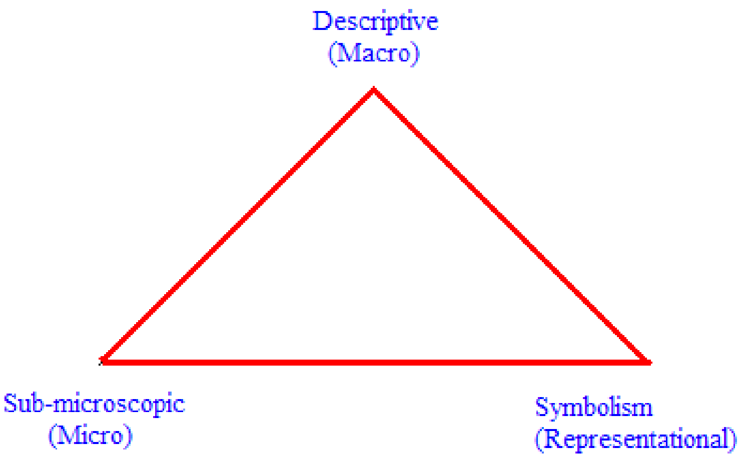

Figure 2.1: Different representational levels in chemistry
(Adapted from Sirhan, 2007)

Chemistry involves three main levels of representation (Johnstone, 1991): macroscopic, (sub-) microscopic, and symbolic levels (Figure 2.1), about which chemists exhibit high fluency through their scientific thinking (Kozma & Russell, 1997; Nakhleh & Krajcik, 1993). The macroscopic level deals with visible phenomena that can be seen with the eye. The (sub)-microscopic level deals with fundamental particles (e.g. atoms, molecules and electrons). The symbolic level involves, for example, chemical formulas and equations.

Understanding of chemical phenomena requires transfer of knowledge among levels. According to Johnstone (1991); Gabel (1992); Harrison & Treagust (2000); Ebenezer (2001); Ravialo (2001); Treagust, Chittleborough and Mamaila (2003), the link between these levels should be explicitly taught. Also, the interactions and distinctions between them are important characteristics of chemistry learning and necessary for achievement in comprehending chemical concepts. Therefore, if students possess difficulties at one of the levels, it may influence understanding of the other. Thus, determining and overcoming these difficulties should be our primary goal.

All representational levels in chemistry are necessary to better understand chemistry. According to Oversby (2000), only a few macroscopic-level observations can be understood without the (sub)-microscopic representational level. The symbolic level is used mostly by chemists to describe chemical phenomena (Kozma, Chin, Russell & Marx, 2000). It is like an international language that chemists use in discourse with colleagues (Justi & Gilbert, 2000).

Chemists use their representational competence in social situations as evidence to support claims, draw interferences, and make predictions about chemical phenomena (Kozma & Russell, 2005). Representations have become a way for scientists to communicate with themselves to conceptualise unobservable concepts that explain phenomena. Students often explain their macroscopic observations using symbolic representations, but chemistry students, even undergraduate students, have little understanding of their observations at the sub-microscopic level (Bodner, 1991; Hinton & Nakhleh, 1999; Johnstone, 1991). According to Gabel (1998), the emphasis in chemistry teaching has focused much more on the symbolic level of representation than on the macroscopic level, since the 1960s.

Johnstone (1984, 1991) indicates that the nature of chemistry concepts and the way the concepts are represented (macroscopic, microscopic, or representational) make chemistry difficult to learn. The methods by which students learn are potentially in conflict with the nature of science, which in turn, influences the methods by which teachers have traditionally taught (Johnstone, 1980).

In order to determine whether student's understanding of chemistry would increase if the particulate nature of matter (sub-microscopic level) was emphasised, Gabel (1993) conducted a study involving students in an introductory chemistry course. Introducing extra instruction to the experimental group that required students to link the particulate nature of matter to other levels (macroscopic and symbolic levels), Gabel found that the experimental group performed higher in all levels than the control group. It seems that this kind of additional instruction is effective in helping students make connections between the three levels on which chemistry can be both taught and understood. Sawrey (1990) found that in an introductory chemistry course, significantly more students were able to solve the problems that used symbols and numbers than those who could solve problems depicting particles. Bunce, Gabel and Samuel (1991) interviewed students who had solved problems out loud. This study indicated that students rarely thought about the phenomenon itself but they searched in their minds until they came upon something that fitted the conditions of the problem.

Osborne and Cosgrove (1983) showed how students (at several school age levels) understood little about the particulate nature of matter or about chemical phenomena in their everyday lives. Surprisingly, some of the incorrect explanations that students gave to common phenomena are concepts that they developed after formal school instruction. Bodner (1991) then used the same questions developed by Osborne and Cosgrove to determine how prevalent these ideas were among the graduate students. His findings indicated that non-scientific explanations persist for some students even after they had graduated with a major in chemistry. He concluded that students have difficulty in applying their knowledge and they do not extend their knowledge into the real world. This last aspect has been discussed (Reid, 1999, 2000) with the suggestion that the chemistry syllabus to be taught should not be defined by the logic of the subject but by the needs of the student. Johnston's complementary paper (2000) emphasises that the order and method of presentation must reflect the psychology of the students. These two fundamental principles would offer a constructive basis for dialogue in re-structuring the way chemistry is offered at school and higher education: in simple terms, define the material to be taught by the needs of the student, and define the order of presentation by the psychology of learning. These ideas with respect to how students learn chemistry bring forth the possibility that discussion and collaborative class exercises could be means of considering students' individual needs and re-structuring the way chemistry is taught and learnt.

It should be noted that such a statement is relatively easy to make but may well prove very difficult to implement. Most curricula are defined by the needs of the next stage and are not defined by the needs of those (often the majority) who will *not* study chemistry at the next stage (Reid, 1999, 2000). Similarly, chemistry is a logical subject and its inherent logic is a tempting structure on which to build a syllabus. However, the logic is that of the expert, not the student.

Aksela (2005), however, claims that science has a social nature. Different kinds of communication (e.g. written and oral) are central within the community of scientists. Much of modern-day science is conducted by groups of scientists rather than individuals, i.e. using distributed reasoning (Dunbar, 1995; 1997; Thagard, 1997). The scientists externalise much of their thinking through interactions with other scientists in the laboratory, and are seen as part of a social group that has a very important role in the creative process (Dunbar, 1999a). Much of laboratory interaction consists of scientists reasoning about all aspects of the enterprise, discussing models, drawing diagrams, making inductions, reaching deductions, discussing competing models, designing, and dissecting experiments. In addition, the possibility of alternate models, methodological errors, and feasibility of various approaches are discussed in the laboratories (Dunbar, 1999b).

Justi & Gilbert (2002) and Nersessian (1999) emphasise that models and modelling are central to how students learn chemistry. All explanations of chemistry phenomena make extensive use of models (Gilbert, Boulter & Elmer, 2000). All modelling in chemistry is undertaken for a particular purpose (Justi & Gilbert, 2002). Models can be used to make abstract entities visible, provide descriptions and/or simplifications of complex phenomena, and to provide a basis for scientific explanations and predictions about phenomena (Gilbert, Justi & Aksela, 2003).

Table 2.1: Different models and representations often used in chemistry and/or chemistry education (Aksela, 2005)

Models	Different Modes of Representations	Different Sub-modes of Representations
Mental A private and personal representation of phenomena (e.g. chemical reaction) formed by an individual either alone or in a group.	**Verbal** Can be spoken or written presentation, for example, of metaphors and analogies upon which the model is based.	**Macroscopic** Observational experience in the laboratory or/and everyday life (e.g. colour change or precipitate formation in a chemical reaction).
Expressed A version of a mental model placed in the public domain (e.g. students discuss their ideas of chemical reactions).	**Symbolic** Can consist of chemical symbols and formulas, chemical equations, and mathematical expressions, particularly equations.	**(Sub)-microscopic** The representation of the inferred nature of entities (e.g. atoms, ions, molecules) and their relationships.
Consensus When any social group (e.g. a small group in an inquiry) agrees on a common expressed model.	**Visual** Using graphs, diagrams, and animations (e.g. two dimensional representations of chemical structures)	**Symbolic** The representation of the identities of entitles (e.g. those involved in a chemical reaction, a "chemical equation").
Scientific A model based on scientific inquiry. It is accepted and used by a group of scientists (e.g. chemists). A superseded scientific model can be called an **historical model** (e.g. Bohr model).	**Gestural** Makes use of the human body or its parts (e.g. hands) to visualize the phenomena.	
Curricular Versions of consensus models that are included in chemistry curricula.	**Concrete** A three-dimensional object made of resilient materials (e.g. a plastic ball-and-stick model of an ionic lattice).	
Teaching Created to support the learning of curricular models and the phenomena that they present (e.g. use of an analogy		
Hybrid Formed for teaching purposes by merging characteristics of several distinct consensus models in a field of enquiry.		
Pedagogy A model that a teacher is using in classrooms (e.g. learning cycle).		

Various kinds of models and representations are used in chemistry and/or chemistry education (Table 2.1): mental, expressed, consensus, scientific, historical, curricular, teaching, pedagogy, and hybrid. Their modes of representation can be usually concrete, verbal, symbol, visual and/or gestural at macroscopic, (sub)-microscopic and/or symbolic levels in chemistry. However, mental models cannot be concrete. Chemists, mainly, use concrete, symbolic, and visual modes of representations (Justi & Gilbert, 2002). These different modes can also be combined. Various modes of representation in 2D (e.g. molecular formula, skeletal, sawhorse, Newman, and Lewis-Kossel), in 3D (e.g. ball-and-stick, space filling, and pseudo-3D representations via computers), and other visual models (e.g. graphs) are often employed in chemistry.

A mental model is the students' personal mental representation of an idea or concept. It is a window into the students' understanding and can be used by the student to give explanations, make predictions and provide reasoning. Mental models are therefore used in this study to explain students' conceptual development of stoichiometry concepts in establishing how students learn chemistry in the SI sessions. The personalised mental model of a student is described by Norman (1983) as hazy, incomplete and messy, and by Brewer (1999), as ambiguous. However, mental models are still considered to be of value.

A mental model has been described as the user's conceptual model, a mental representation, a mental image, an internal representation (Bodner & Domin, 2000), a mental process, an unobservable construct (Hennessey, 2003), a personal cognitive representation and an internal model (Gilbert, Boulter & Elmer, 2000). Incorporating these descriptions, mental models can be considered on two levels (Brewer, 1999):

- Representations of specific information that are imitations of reality.
- A subclass of theories or constructed schemata that are explanatory frameworks.

These two broad levels can be associated with the representational and evaluative levels that Hennessey (2003) has used in assessing the meta-cognitive processes associated with learning. A mental model is not just the picture in the students' mind; it incorporates the ontological network that students have personally constructed and use to assimilate new ideas. In understanding new concepts, students look for patterns and commonalities with concepts that are already understood. This relates to educators or SI leaders promoting strategies, identifying commonalities, grouping, and identifying differences so that students are able to construct or envision a personal mental model. This approach is consistent with a constructivist approach and the ontological perspective of conceptual change learning theory in the way knowledge is constructed, which will be discussed further in the next chapter.

The personal mental model provides insight into the students' mental processing of information. The status of the students' mental model is a reflection of their understanding. The personalised mental model of the student is, according to Norman (1983), incomplete, undergoing constant modifications, unstable because students forget the detail that was needed to construct the model and not necessarily technically accurate but functional. In developing a better understanding of how students learn chemistry, in particular stoichiometry, it is significant to understand the role of mental models in interpreting the engineering students' engagement in chemistry SI sessions.

2.7. The Mental Model and Conceptual Change

It is interesting to note the role mental models play in students' responses to group discussions in chemistry SI sessions, as Norman (1983) indicates that the primary purpose of a mental model is predictability. Students test, validate and confirm their understanding by running their mental model, making predictions and inferences based on their understanding of a particular concept. The feedback they receive from the inferences and predictions may cause them to modify their thinking or it may confirm their ideas. There is no evidence of learning without feedback and testing of understanding. This recursive process, often resulting in changes to the students' mental models, is an integral component of the conceptual change process. The student, evaluating and revaluating concepts in light of new explanations, quickly and repeatedly perform the recursive behaviour. The SI programme is based on SI leader and peer feedback which are regarded as important aspects of the SI learning process and is also found to be consistent with the social constructivist view of learning.

2.7.1. Instrumental/Relational Learning

Skemp (1976) used the students' mental model of the schema of knowledge to provide insight into the students' understanding. He differentiated rote learning from meaningful learning on the basis of the interconnectedness of the students' knowledge schema. Rote-learning is described as being easier and quicker to grasp, with a proposed knowledge schema represented by discrete units which reflect an instrumental level of understanding, whereas meaningful learning is represented by a linked and interconnected schema of knowledge learning which reflects a relational level of understanding that is adaptable to new tasks and is "organic in quality" (Skemp, 1976: 24).

The significance and the subtlety of the differences between these two types of learning is that the students may know the same facts of the subject but their way of knowing is different (Skemp, 1976). This epistemological perspective draws attention to the importance of foundation learning being presented *in situ* as part of a conceptual structure or schema. SI sessions in contrast attempt to develop a deeper understanding of concepts through reflection, explanation and redirecting questions which also aim at developing students' foundation learning. This complements the theory of conceptual change whereby the way of knowing corresponds to the student evaluating the intelligibility, fruitfulness, and plausibility of new ideas.

Although Skemp (1976), differentiates between rote and meaningful learning, rote-learning can be valuable learning and is often the most appropriate learning style for particular situations (Battino, 1992). This is especially true for certain aspects of chemistry (learning of equations, units, etc.) when students need to build a foundation for future learning. It is therefore assumed that students use multiple learning styles in developing their conceptual understanding and it is evident that mental models are significant for the different learning styles.

2.7.2. Mental Models in Chemistry

Students' mental models, which are built up through their experiences, interpretations and the explanations that they use, reflect their understanding of the sub-microscopic level of chemical representation of matter. Students' mental models are a function of the ideas, experiences, images, models and other resources that the student has experienced, so the teacher or in this case the SI leader, has a significant effect on the students' mental model because he or she is often introducing these new ideas and concepts. Research in chemistry has shown that students' cognitive organisation of knowledge is surprisingly weak (Taagepera and Noori, 2000). Mental models are essential for the necessary tasks of learning chemistry including making predictions, testing new ideas and solving problems (Bodner and Domin, 2000).

The ontological organisation of ideas by the student forms the basis of the mental model and generating an interconnected schema of knowledge which, as Skemp (1976) describes, should promote more meaningful learning. The SI programme also attempts to identify teaching and learning strategies that promote this process, such as concept mapping, discussion and predict-observe-explain tasks.

Keen students, intent on learning, consciously undertake meta-cognitive tasks to improve their understanding, and of being aware of why and how the tasks are enhancing learning (Bransford, Brown and Cocking, 2000). The mental activity associated with learning produces mental models that are in essence the students' understanding of the concept. The students' recognition of their personal mental models and the meta-cognition of thinking about how and why they have developed, form the foundation of the learning process.

The mental model, which is constantly under review, reflects a students' ontological network of knowledge. Students construct mental models and then use them for tasks such as solving problems, answering questions or making predictions. However, Chittleborough, Treagust and Mocerino (2002) have shown that students tend to resort to simple mental models of chemical phenomena even if they have learnt more sophisticated models, indicating a lack of confidence in the chemical knowledge schema.

2.8. Research on Stoichiometry

In this section a brief explanation of the concept of stoichiometry is given. It also highlights research on difficulties, misconceptions and possible reasons for these difficulties experienced by students with respect to stoichiometry problem-solving both nationally and internationally.

According to Okanlawon (2010), stoichiometry is a branch of chemistry which provides quantitative information about chemical reactions which involves problem solving where students are given the amount of one substance in a chemical reaction and are required to calculate the amount of another substance necessary to react completely with the given substance, or the amount of substances produced in the chemical reaction. Sample problems to be encountered when dealing with stoichiometric calculations are:

(1) How much magnesium (II) oxide (MgO) will be produced if 3.00g of magnesium ribbon is burnt in the air?

(2) How much magnesium and oxygen are required to produce one ton of magnesium oxide?

There is a consensus among chemistry educators that learning to solve those problems requires a good mastery of chemistry concepts, ability to construct and balance chemical equations and using the balanced chemical equations to calculate the masses of chemical substances involved in the reactions.

Stoichiometry is regarded as one of the fundamental 'tools in the chemistry toolbox' (Evans, Leinhardt, Karabinos, Yaron, 2006) because attainment of a high degree of proficiency in solving stoichiometry problems is needed for dealing with equilibrium and acid-base problems. Unfortunately, stoichiometry calculations have always been difficult for students (BouJaoude & Barakat, 2000; Furio, Azcona and Guisasola, 2002; Fach, Boer and Parchmann, 2007). The reasons for this difficulty lie in the complexity of conducting these calculations that require an understanding of the mole concept, which is an abstract concept; constructing and balancing chemical equations, algebraic skills, and interpretation of a word problem into procedural steps that lead to the correct answer Okanlawon (2010).

Embarking on research that highlights students' ways of knowing stoichiometry will assist both students and educators in developing skills in knowing and ways of developing a deep understanding of stoichiometry, beyond surface approaches to learning (Leithwood, McAdie, Bascia, and Rodrigue, 2006).

There has been a vast amount of research that has covered stoichiometry problems in recent years (see Gabel & Bunce, 1994: Griffiths, 1994 and Furio et al., 2002). This is so because students have to switch from thinking about concrete aspects of matter to more abstract thinking concerning aspects of particles (BouJaoude & Barakat, 2003). However, many authors agree that the concept is very difficult for students to grasp and therefore discouraging (Schmidt and Jigneus, 2003). It would therefore be very interesting to note how engineering students engage in collaborative learning tasks in chemistry SI and how SI influences stoichiometry knowing, and the development of a deeper understanding of stoichiometry concepts.

A considerable amount of research has indicated that students bring with them to science classrooms certain ideas, notions and explanations of natural phenomena that are not consistent with the consensus of the scientific community and are regarded as misconceptions (Wanderersee, Minitzes and Novak, 1994). Students bring these misconceptions to the study of stoichiometry which strongly influence learning and understanding. There is a wealth of literature on the misconceptions students hold in stoichiometry (BouJaoude & Barakat, 2000; Furio, Azcona & Guisasola, 2002; Fach, Boer & Parchmann 2007; Mitchell & Gunstone 1984; Schmidt 1990; Huddle & Pillay, 1996). This literature provides ample evidence that chemistry students have misconceptions in the sense that:

- They equate the mass ratio of atoms in a molecule with the ratio of the number of these atoms, and the mass ratio with the molar mass ratio (Schmidt,1990);
- They calculate the molar mass of a given substance by summing up the atomic masses and then multiplying or dividing this sum by the coefficient of the substance in the chemical equation; others do not understand the significance of the coefficients in a chemical equation at all (BouJaoude & Barakat, 2000);
- They confuse the concepts of conservation of atoms and possible non-conservation of molecules or do not take into account the conservation of atoms or mass at all (Mitchell & Gunstone 1984) ;
- They cannot determine the 'limiting reagent' in a given problem, when one substance is added in excess (Huddle & Pillay 1996);
- They confuse or do not know the definitions of and relationships between stoichiometric entities in general (Furio, Azcona & Guisasola, 2002);
- They believe that one mole means the same as one particle (Fach, Boer & Parchmann, 2007).

Okanlawon (2010) states that the above mentioned misconceptions can interfere with learning to solve stoichiometric problems, since solving stoichiometric problems requires both conceptual understanding and mathematical skills. It is believed that because students lack understanding of the fundamental concept of chemical stoichiometry (the particle description of atoms/molecules, the mole concept, concept of solution and chemical change) and the required mathematical skills, they are unable to draw the proper relations among various concepts and the quantitative representation of these concepts. Researchers have found that success in solving mathematical or algorithmic exercises does not indicate mastery of chemistry concepts (Stamovlasis, Tsaparlis, Kamilatos, Papaoikonomou & Zarotiadou, 2004).

According to Fach, de Boer & Parchmann (2007), researchers provide general advice with respect to challenges experienced in the teaching and learning of stoichiometry, but specific methods based on empirical data are rarely provided. This notion is corroborated by a questionnaire study conducted in Germany to which they make reference, where teachers were asked which topics of chemistry were difficult to teach and why (Fiebig & Melle, 2001). The issue of ‘basic chemical laws’ (including stoichiometry) was conveyed as 'difficult to teach' partly because of a lack of suitable teaching methods. This study, which explores student engagement with stoichiometry concepts within an SI environment with an emphasis on teaching and learning methods, envisages filling the gaps with respect to research based on empirical data. Also, as is evident in the literature just surveyed, stoichiometry poses many challenges in teaching and learning because of its abstract reasoning skills and prerequisite mathematical knowledge which is essential for the understanding of stoichiometry concepts. First year under-preparedness and the lack of abstract reasoning skills thus present an additional bottle neck in the understanding of stoichiometry concepts.

2.9. Engineering students' engagement in higher education

Literature indicates a general trend in engineering education in the last decade towards addressing challenges of globalisation of the economy (Bradshaw, 2010) and the demographic changes of universities (Fraser, 2007), both nationally and internationally. The challenges of globalisation have resulted in the educational vision to improve graduates' analytical problem-solving skills, technical skills and collaborative skills, in ways that enable them to engage in modern challenges in engineering. Changes in university demographics have resulted in large class sizes, under-prepared first year students, increasing drop-out rates and decline in throughput rates.

Brussow and Wilkinson (2010: 375), indicate that "initiatives to provide a supportive learning environment for students who are under-prepared for higher education are critical, not only to improve academic achievement but also to develop in these students the way to learn". To develop 'the way to learn' they focused on engaged learning which entails the creation of an educational environment that encourages student engagement in the learning process as learning scaffold. Brussow and Wilkinson refer to Boylan (2001: 2), where it is suggested that various factors contribute to academic performance. He emphasises that lacking reading, writing and mathematical skills, under-preparedness, self-efficacy, independence, study skills and social ability have an effect on academic success.

Zyngier (2007), claims that student engagement has been identified as an important precursor to student learning and challenges how we might conceive of student engagement in order to achieve the twin goals of social justice and academic achievement. As mentioned previously, Kearsley & Shneiderman's (1999) model underlying engagement theory is that students must be meaningfully engaged in learning activities through interaction with others and worthwhile tasks. They refer to engaged learning in terms of all student activities involving active cognitive processes such as creating, problem solving, reasoning, decision-making, and evaluation. As such, they focus on the twin goals of social justice and academic achievement. In addition, students are intrinsically motivated to learn given the meaningful nature of the learning environment and activities. Kift and Field (2009) agree with this notion of student engagement in the first year of tertiary study, this time being of particular significance and importance in improving the quality of higher education, making deep learning outcomes possible for students, and achieving student retention.

To consider engaged learning as a means of assisting under-prepared students, Brussow and Wilkinson (2010) have looked into the concept of 'engagement', firstly to express a myriad of student actions and thoughts which are believed vital to a high quality undergraduate learning experience (Krause, 2005). Lederman (2006) proposed that engaged learning supports the underprepared students and even makes a more significant contribution to these students' learning and academic achievement. The findings of the latest annual National Survey of Student Engagement (NSSE) stated that the academic performance of underprepared as well as racially and ethnically underprepared students improved through being 'engaged' both academically and socially in the higher education environment (Wasley, 2006).

Brussow and Wilkinson (2010) revealed a graphical representation of a potential engaged learning structure based on the results of their study that investigated engaged learning potential to scaffold the under-prepared students in developing

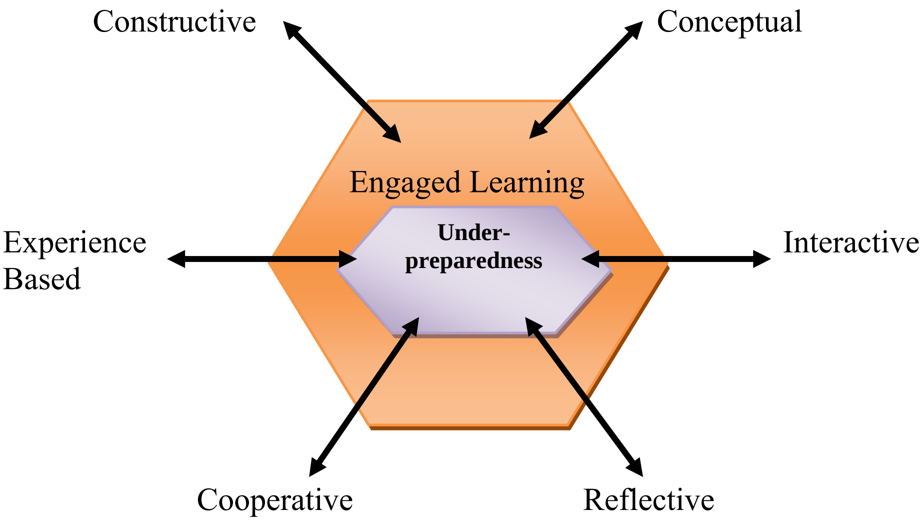

Figure 2.2: Engaged learning model (Brussow & Wilkinson, 2010:388)

the academic skills of effective learning. The six teaching and learning approaches represented by the hexagon are overlapping and interconnected and reinforce one another, as illustrated by the web between them. The web further denotes the importance of a sustaining and involved learning environment that is needed to scaffold successfully the under-prepared students in their progress through higher education.

This study seeks to explore engineering students' engagement in chemistry SI in developing an understanding of stoichiometry concepts. It is evident that the engaged learning model by Brussow & Wilkinson (2010) supports the teaching and learning approaches used by SI (see research methodology chapter) in maintaining student engagement. SI has constructivism as its theoretical foundation[13]; it functions on the premise of collaborative learning[14] and is therefore interactive in nature. It draws on students' prior knowledge so it is experience-based, and the SI leader assists students in reflecting on their learning and consolidating their understanding of strategies and skills through asking probing questions. Lastly, SI is cooperative in nature as it is based on group and peer learning activities. It is therefore argued that SI has the

[13] Discussed in Chapter Three of this study.
[14] As discussed in this chapter, section 4.

potential to provide a supportive and engaged learning environment for under-prepared students in higher education.

2.10. Conclusion

This chapter firstly argues for the framing of SI as *context* with respect to its role within an institutional *context*, the *context* of engineering and the pedagogical *context* of chemistry, whereas SI as *concept* is viewed with respect to collaborative learning practices. SI as *concept* and *context* are important framing measures in this thesis in understanding students' engagement in chemistry SI sessions.

Secondly, literature was reviewed with respect to the nature of chemistry learning, with special emphasis on meaningful learning approaches, and how students get to know chemistry concepts with reference to the use of mental models in developing an understanding of chemistry concepts. The literature revealed that models played an important role in understanding how chemistry is learnt; hence this chapter looked at several models to give a clear understanding of how stoichiometry in higher education can be taught and learnt. Students' learning of stoichiometry concepts was highlighted, reflecting their difficulties in learning stoichiometry concepts most especially because of the abstract reasoning skills and prerequisite mathematical knowledge that is required for the understanding of these concepts. Lastly, engineering students' engagement in higher education was examined with particular reference to improving first year students' under-preparedness for higher education, where research reflects the importance of a sustaining and involved learning environment that is needed to scaffold the under-prepared students in their progress through higher education.

It is evident from the above discussion that there are individual and social aspects that influence learning. The evolution of ideas and understanding is a dynamic but gradual process that is personal for each student. The evaluation of ideas in terms of their plausibility, intelligibility and fruitfulness is undertaken by the student accidently, surreptitiously or intentionally but is influenced by the students' own epistemology, ontological network and motivation (Duit and Glynn, 1996).

Given this background to the study and the available literature, the context is now set for some understanding of the theoretical frameworks that underpin this study.

CHAPTER THREE

THEORETICAL FRAMEWORK: SOCIAL CONSTRUCTIVISM, CONCEPTUAL CHANGE THEORY AND META-COGNITION

3.1. Introduction

The theoretical framing of this study will be discussed with respect to social constructivism, conceptual change theory and meta-cognition. These theoretical frameworks are gazed at with respect to engineering students' engagement within a social constructivist paradigm, how students achieve conceptual change during SI engagement and finally, how students move between conceptual change and cognitive levels in becoming aware of their cognitive processes (meta-cognition). In other words, how students' social engagement leads to their conceptual development and knowing of stoichiometry concepts is examined.

3.2. Social Constructivism

Internationally, engineering schools grapple with how best to prepare effective engineers in the twenty-first century. There is a move from transmission models of learning and teaching towards constructivist models. SI has constructivism as its theoretical foundation and bears many similarities to problem-based learning approaches, as they function on the premise of collaborative learning. SI is based on three fundamental ideas, viz. the idea of interaction as a prerequisite for learning, the idea of meaningful conditions for learning and the idea of questioning in a way that promotes the development of concepts (Mannikko-Barbutiu & Sjogrund, 2004).

Social constructivism is closely associated with many contemporary theories, most notably the developmental theories of Vygotsky and Bruner, and Bandura's social cognitive theory (Kim, 2001). "The social constructivist version of Vygotsky, who in an effort to challenge Piaget's ideas developed a fully cultural psychology stressing the primary role of communication and social life in meaning formation and cognition" (Boudourides, 2003), bears relevance. According to Bruffee (1983), Vygotsky's main link to constructivism derives from his theories about language, thought, and their mediation by society.

3.2.1. Social Constructivism and learning

The notion of social constructivism has been given many interpretations. This perspective provides authentic learning situations (Roth, 1995), situated cognition (Brown, Collins & Dugid, 1989) and cognitive apprenticeships (Hodson & Hodson, 1998b), that describe a way of knowing. Strongly influenced by the work of Vygotsky (1934/1986), this school of thought argues that knowledge is constructed first on a social plane, and then internalised. Vygotsky's theories stress the fundamental role of social interaction in the development of cognition (Vygotsky, 1978; Wertsch, 1985), as he believes strongly that the community plays a central role in the process of "making meaning." (Vygotsky, 1978) describes the zone of proximal development where learning takes place in discussions between students who have reached different levels in their individual learning and who can benefit from each others' learning experience and knowledge. This theory is central to SI where students arrive at solutions through common understanding which is developed through probing, modelling and questioning. This guides the novice closer to a more scientific representation of the task at hand (Lee, 2000). The learning context is considered social in that the student does not acquire scientific concepts in isolation. Authors who adhere to this view and consider knowing and learning in terms of culture and practice are abundant (for example, Lave & Wenger, 1991; Brown, Collins & Duguid, 1989, and Cobb, 2001). These authors argue that learning is social and comes largely from our experience of participating in our daily life however; their conception of how this social learning occurs differs. Learning models based on the social constructivist perspective stress the need for collaboration among students and with practitioners in the society (Lave and Wenger, 1991; McMahon, 1997).

Jean Lave and Etienne Wenger proposed that learning involved a process of engagement in a 'community of practice'. Wenger's (2000:64) conception of a ''community of practice'' offers a possible model for a classroom that could facilitate learning through social interaction which coheres with Vygotsky's notion of the zone of proximal development. Lave and Wenger (1991) assert that a society's practical knowledge is situated in relations among practitioners, their practice, and the social organisation and political economy of communities of practice. For this reason, learning should involve such knowledge and practice (Lave & Wenger, 1991; Gredler, 1997). This has significant implications for SI teaching and learning as a medium of communication. The goal of this type of approach is the achievement of 'communities' of students working in small collaborative groups to achieve a common goal (Dillenbourg and Schneider, 1995). Wenger described learning as taking place within collective activity in which individuals provide scaffolding for each other to acquire the skills and knowledge for participation.

According to social constructivist learning theory, there is also a responsibility for the teacher. In this study, the SI leader has to provide learning opportunities in Vygotsky's zone of proximal development (ZPD) by scaffolding and including socially negotiated learning (Howe, 1996). Scaffolding in this study would refer to the SI leader introducing appropriate learning tasks that are initially beyond the student; with instructions and interactive tasks, the student can advance his/her development to work independently without any scaffold or assistance (Hodson & Hodson, 1998a). Vygotsky defines ZPD as "the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotaky, 1978: 86). He asserts, "...what is in the zone of proximal development today will be the actual development level tomorrow - that is, what a child can do with assistance today she will be able to do by herself tomorrow" (Vygotsky, 1978: 87).

Through the concept of ZPD, Vygotsky determines that learning precedes development. Students must engage with material that consistently maintains engagement within the ZPD so that development will proceed without lapse. If a student works with learning material that is too simple or too difficult, or the adult or peer does not mediate the learning activity adequately, then development does not occur and frustration often results. Fosnot and Perry (2005: 23) offer further clarity on

Vygotsky's view of the ZPD by explaining it as a place where a student's "spontaneous concepts" work their way "up" to meet an adult's (or peer's) "scientific concepts", working their way "down" within this ZPD. Logic is imposed and accepted in this dialogic interaction. According to Smagorinsky, Cook and Johnson (2003), spontaneous concepts are learned through cultural practice and scientific concepts are learned through formal instruction.

Further, the ZPD is social in nature, in keeping with Vygotsky's socio-cultural history theory. An essential feature of learning is that it creates the zone of proximal development: "learning awakens a variety of internal developmental processes that are able to operate only when the student is interacting with people in his environment and in cooperation with his peers. Once these processes are internalized, they become part of the child's independent developmental achievement" (Vygotsky, 1978: 90).

Termed "social situation of development", students experience a contradiction between current abilities, individual interests, and what the environment will afford. They then engage in learning activities to resolve such contradictions thereby continuing the development of any given internal function or creating new functions to cope with the situation (Chaiklin, 2004: 47). By using elements of the ZPD, SI Leaders can provide an important tool to assist students at their appropriate learning and developmental levels. Then, as students increase their developmental levels, the creation of dialogue between a novice and an expert occurs that then leads to an inner dialogue. Vygotsky labels this phenomenon inner speech which is a component of deep understanding of the material (Reiber & Carton, 1987).

Closely aligned to Vygotsky's theory of the zone of proximal development, is that of Johnson and Johnson (1991), who indicate that social interaction leads to advanced cognitive development and promotes higher academic achievement than individual learning activities do. This assumption should also be applicable to the SI learning environments which function on collaboration and discussion amongst peers and SI leader. Merrill and Gilbert (2008) confirm this claim by suggesting that peer-collaboration requires deeper processing for students to make their intent clear to their collaborators. In doing so, it encourages students towards a deeper processing of the information and a more careful examination of their assumptions. It is therefore argued that Vygotsky's theory on the 'zone of proximal development' can be considered to understand students' engagement in chemistry SI.

3.2.2. Features of Social Constructivism

Language as a cultural tool provides the primary means with which two students engage in dialogue, and the construction of knowledge follows. Social constructivism shows that learning is not a purely internal process, nor is it a passive shaping of behaviours. Vygotsky favoured a concept of learning as a social construct which is mediated by language via social discourse (McMahon, 1997). The most significant moment in the course of intellectual development, which gives birth to the purely human forms of practical and abstract intelligence, occurs when speech and practical activity, two previously completely independent lines of development, converge (Rogoff, 1990). A key aspect for this theory is that knowledge is socially constructed and thus contested.

Mediation is also a critical part of Vygotsky's model as an opposite response to previous theories of acquisition (Kozulin, 2003). The student must apply psychological tools found in the SI environment to the process of mediation in order to achieve higher mental development. Such tools, according to Kozulin, were established by Vygotsky as part of formal education (symbolic artefacts such as signs, symbols, texts, formulae, graphic organisers), but they may also include other human beings (SI leaders) or organised learning activities like scaffolding or apprenticeship models.

While Vygotsky was a psychologist, his work late in his life turned to using his socio-cultural history construct in a pedagogical sense, focusing on language and social interaction in classroom learning situations. Strengthening Vygotsky's knowledge construction are the ideas of philosopher John Dewey, whose curricular contributions with respect to experiential learning provide another context of space in which to consider Vygotskian notions and further clarify socio-constructivist thought (Sullivan, 2005).

Experiential learning theory offers a dynamic theory based on a learning cycle driven by the resolution of the dual dialectics of action/reflection and experience/abstraction. These two dimensions define a holistic learning space wherein learning transactions take place between individuals and the environment. The learning space is multi-level and can describe learning and development in commensurate ways at the level of the individual, the group, and the organisation (Kolb & Kolb, 2008).

Taylor, Geelan, Fox & Herrmann, (1997) show that social constructivism combines both the constructivism and critical theories of learning. They argue that from constructivist theory emerges a view of learning as a process of constructing new knowledge within the mind by reflecting on the viability of one's existing knowledge in light of new experiences, and a socially-mediated process of negotiation of meaning amongst a community of learners. From critical theory comes the view of an empowered student as one who seeks to understand other students' understandings through an interest in open communication, and reflects on oneself critically on the unconscious and shared beliefs and values that shape routine social practices.

Criticism levelled against social constructivism refers to the type of learning it supports. Taylor et al (1997) argue that while it may be true that social negotiation is a useful approach to achieving consensual understanding of ill-structured subject matter, even in the 'softest' subjects there is often a body of undisputed knowledge. This study embraces social constructivism because UKZN has a rich diversity of students and the theory accommodates the diversity of languages and cultures, amongst other things. One of the pillars of social constructivism is language, through which people make meaning, via negotiation, interact socially, politically, economically, culturally and spiritually. Social constructivism therefore supports the goals of multilingualism that afford students the opportunity to develop an understanding of conceptual knowledge through a shared or common understanding of concepts after dialoguing with peers.

Kim (2001) raises specific assumptions about social constructivism, which include reality, knowledge and learning. Social constructivists believe that reality is constructed through human activity where members of a society, in this case the SI society, together invent the properties of the world (Kukla, 2000). Thus, reality cannot be discovered as it does not exist prior to its social invention. Constructivists also believe that knowledge is a human product that is socially and culturally constructed (Gredler, 1997). Individuals create meaning through their interactions with each other and with the environment in which they live. Learning is, therefore, a social process. It does not take place only internally, nor is it a passive development of behaviours that are shaped by external forces (McMahon, 1997). Social constructivist perspectives on teaching and learning emphasise the cognitive and social activity of students in co-constructing their knowledge (Taylor et al., 1997). Thus meaningful learning occurs when individuals are engaged in social learning activities. Chemistry SI engages students in collaborative learning activities which has the potential to create meaningful learning opportunities.

When interaction has a direct influence on a student's intellectual growth, we can say the interaction is meaningful (Hirumi, 2002; Vrasidas & McIssac, 1999). Hence in an SI learning environment designed on the principles of social constructivism, meaningful interaction should include responding, negotiating internally and socially, arguing against points, adding to evolving ideas, and offering alternative perspectives with one another while solving some real tasks (Jonassen, Davidson, Collins, Campbell & Haag, 1995; Lapadat, 2002; Lave & Wenger, 1991; Vrasidas, 2000; Vygotsky, 1978). Figure 3.3 illustrates the concept of meaningful interaction in social constructivism as depicted by Woo & Reeves (2007:19).

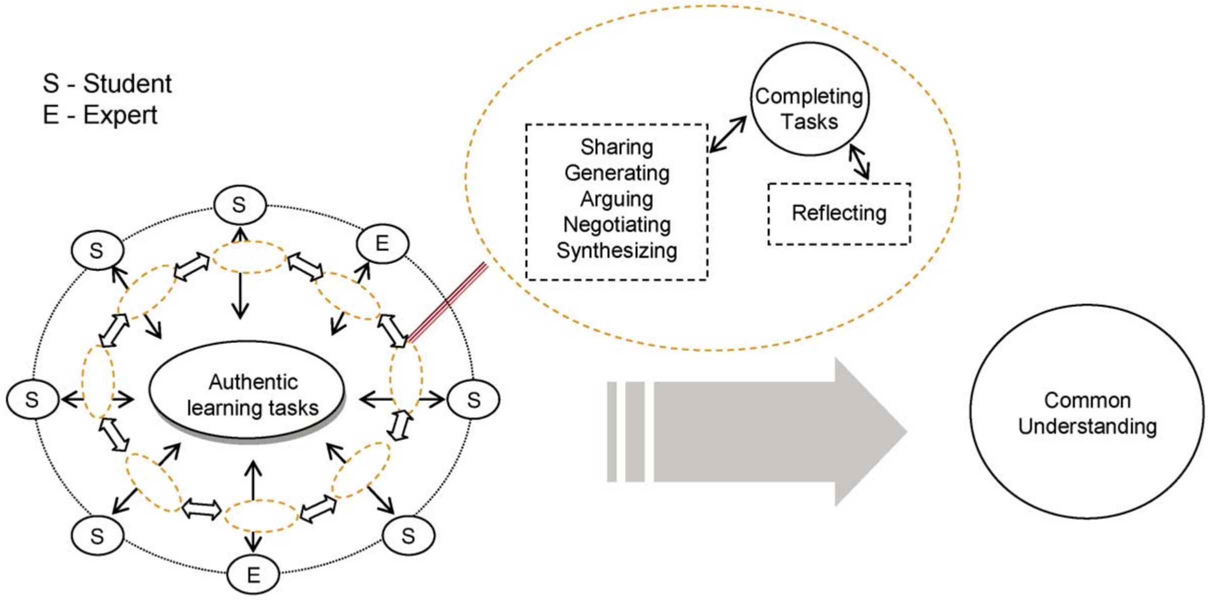

Figure 3.3: **Meaningful interaction in social constructivism** (Woo & Reeves, 2007)

While engaging in authentic learning tasks with various people including peers and experts, students engage in defining the task, generating ideas, sharing resources and perspectives, negotiating, synthesizing individual thoughts with those of others, completing the tasks, and refining them on the basis of further sharing of insights and critiques. When students are faced with confusion or conflict, they discuss the issues with one another at first, and then try to negotiate internally and socially to solve the problem. Finally, they arrive at some common understanding. Such a meaningful interaction process is required for meaning making and hence learning.

According to Doolittle and Hicks (2003), traditionally, the search for knowledge within the social studies consisted of the search for “truth”, that is, the acquisition of knowledge that mirrors or corresponds to a singular “reality” as is typical of chemistry learning. Constructivism, however, employs a more flexible, culturally relativistic, and contemplative perspective, where knowledge is constructed based on personal and social experience. Socio-constructivist practice is democratic and inclusive as it provides for student direction of the curriculum and encourages personal responsibility for learning (Donlevey, 2000; Shapiro, 2000).

In this study it is therefore assumed that students' social interaction within the SI environment can influence meaningful learning of stoichiometry concepts through discussions between students who have reached different levels in their individual learning, and who can benefit from each other's learning experience and knowledge, encouraging personal responsibility for their learning.

3.2.3. Socio-constructivist pedagogy

Socio-constructivism may be traced from its grounding roots in philosophy, through various theoretical tenets and conceptions and, finally, to its practical use in the classroom by teachers and students. Throughout the 20th and 21st centuries, socio-constructivist thought has developed and become accepted as a viable learning theory, ripe for adaptation to pedagogical principles (Fosnot, 2005; Richardson, 2003). In addition to Richardson's (2003) work, Fosnot (2005) provides a comprehensive definition of socio-constructivism and socio-constructivist teaching. A discussion of her definition of socio-constructivism follows:

Based on work in psychology, philosophy, science, and biology, the theory describes knowledge not as truths to be transmitted or discovered, but as emergent, developmental, non-objective, viable constructed explanations by humans engaged in meaning-making within cultural and social communities of discourse. Learning from this perspective is viewed as a self-regulatory process of struggling with the conflict between existing personal models of reality as a human meaning-making venture with culturally developed tools and symbols, and further negotiating such meaning through cooperative social activity, discourse, and debate in communities of practice.

The discussion above suggests that a social constructivist approach to teaching and learning provides students with the opportunity for concrete, contextually meaningful experience through which they can search for patterns; raise questions and model, interpret, and defend their strategies and ideas (which is typical of any SI session). The classroom in this model is seen as a mini-society, a community of students engaged in activity, discourse, interpretation, justification, and reflection (Fosnot, 2005).

3.2.4. The characteristics and applications of social constructivism

Social constructivism is characterised by an active construction of knowledge based on experience with and previous knowledge of the physical and social worlds (Jaworski, 1994; Ernest, 1995). Its main emphasis is on the need for ZPD, the influence of human culture and the socio-cultural context, recognition of the social construction of knowledge through dialogue and negotiation, the inter-subjective construction of knowledge and multiple interpretations of knowledge.

With respect to social constructivism applications the emphasis is on the critical role of peers, in particular more skilled students; the enculturation of students into the community of the particular academic discipline or profession; the use of relevant and authentic tasks; appreciation of multiple perspectives; problem solving in real world situations; collaboration in the learning process; the opportunity for students to publicly share their work, revise their work based in social critiques, and reflect on what they have learned with others (Sullivan, 2005).

This study can be thought of in terms of drawing on social constructivism at a macro level[15] of theorising as it provides a way of understanding students' engagement with chemistry in SI which is based on three fundamental ideas: interaction, meaningful conditions for learning and questioning techniques (Mannikko-Barbutiu, 2004). SI sessions are therefore aimed at conceptual development through collaborative learning strategies.

[15] Social constructivism is regarded as the main over-arching theoretical framework of this study.

3.3. Conceptual Change Theory of Learning

Most of general chemistry content, at the high school and university levels, is still taught and assessed in terms of facts, algorithms and procedural knowledge without emphasis on conceptual understanding (Hesse & Anderson, 1992; Phelps, 1996). Potgieter (2010) extends this view by suggesting that the instruction usually focuses on content breadth without a consistent emphasis on in-depth understanding and integration across concepts. It is often incorrectly assumed that students' procedural knowledge will translate into the development of conceptual understanding (Sawrey, 1990; Phelps; 1996)

The personal construction of ideas consistent with a constructivist theory of learning reveals why and how students have scientifically incorrect understandings – sometimes referred to as misconceptions or alternative conceptions (Chapter Two, section 5). Students assimilate many experiences and ideas, generating their own conceptual understandings before and while they are introduced to the scientifically accepted theories. Commonly, students maintain two contextually independent and conflicting understandings – everyday and scientific (Renstrom, Andersson & Marton, 1990).

Piaget & Inhelder (1958) distinguished between students who can reason at an abstract level versus a concrete level. They claimed that many students in college reason at a concrete level, which means that students have difficulty processing the unfamiliar information they often receive in lectures and textbooks. This is so because they are incapable of linking this new information with prior knowledge they have in the domain, and questions they ask tend to be detail-oriented and at a superficial level. According to Marra & Litzinger (2002), SI can assist in conceptual change by moving concrete thinkers to an abstract level where the SI leader is responsible for creating a learning environment in which students are actively processing lecture content knowledge towards the goals of a) making connections between what students already know and the new knowledge, in order to provide a synthesized knowledge domain; b) applying their new knowledge to applicable domain problems, and c) thinking about their study and learning strategies as applied to the course.

3.3.1. Individual Conceptual Change

Investigating the way that students generate a new understanding of scientific concepts is called the theory of conceptual change, according to Strike & Posner (1982). A student who is dissatisfied with his/her current understanding will evaluate new ideas in terms of:

- Intelligibility – is it understandable to the student?
- Plausibility – is it reasonable and consistent with the students' understanding?
- Fruitfulness – is it of value to the student?

In this way, the students' assessment of the status of a concept is pivotal to its acceptance (Hewson & Thorley, 1989). So the scientific concept has to be more understandable, reasonable and of more value to the student than a rival conception for it to be accepted (Hodson & Hodson, 1998a; Posner et al., 1982). By introducing new and often provocative ideas through collaborative discussion as is evident in SI, a student's accepted conceptions may be challenged, forcing a conceptual conflict that requires each student to re-evaluate his/her understanding. Indeed, expressing their understanding in public can facilitate the process of conceptual change (Hennessey, 2003).

The change of meaning connected with learning and conceptual change has been associated with changes to students' ontological frameworks. Chi (1992) distinguished two levels of conceptual change: conceptual change occurring within an ontological category and radical conceptual change requiring the student to shift between ontological categories. According to Chi (1992: 179), the latter is "nearly impossible to accomplish". The former is more common, with conceptual change more likely to be a gradual development of ideas and understanding in conjunction with the incremental changes to the students' ontological framework of knowledge. Such changes result in the evolution of ideas which could be assisted through class discussions in SI rather than a revolution (Harrison & Treagust, 2001), and it may be difficult to pinpoint conceptual change. Conceptual change within an ontological category does not imply that it is simple, easy or common (Chi, 1992).

3.3.2. Multiple Perspectives of Conceptual Change theory

In order to understand students' engagement and learning in chemistry SI, the multiple theoretical perspectives of conceptual change will be explored, with respect to students' conceptual understanding of epistemology, ontology and social/affective aspects. Here learning is believed to be a multi-faceted process that may involve one or many theoretical frameworks.

3.3.2.1. Epistemological perspective of Science

Epistemologies of science refer to students' understanding of how scientific ideas are built up, including their knowledge about the process of knowing about scientific knowledge (Songer & Linn, 1991). Teachers or SI leaders are role models, modelling the thinking required to understand a concept. Students are often dependent on their teacher or SI leader as their primary and often only source of chemical explanations. Students' epistemology, that is, their understanding of how chemical ideas are built up, does influence their learning. Research has shown that students' background knowledge does influence their ideas and that students generally do hold a surprisingly wide range of ideas that are resistant to change (Gabel, 1999; Taber, 2002).

Students' views of science and its processes develop over time and are shaped and influenced by a variety of factors such as learning institution, home, media and technology. Such views, which are all part of the students' epistemology, are a gauge of students' knowledge, their process of knowing and their understanding of how ideas are built up. The personal nature of students' epistemologies has a significant impact on their learning and is considered to be important in a teaching and learning approach informed by constructivism, such as SI. Duit and Tregust (1998:5) argue that "learning science is related to students' and teachers' conceptions of science content, the nature of science conceptions, the aims of science instruction, the purpose of particular teaching events, and the nature of the learning process".

Pearson, Kamil & Barr (2000) state that in order to succeed in a course, students must understand their professor's objectives and goals, build an awareness of how professors think about their domain and learn how to organise that information. SI sessions are an ideal forum for teaching students how to interpret academic tasks such as realising course objectives and interpreting effective study strategies and skills (Arendale, 1994).

3.3.2.2. Ontological Perspective of Science

The learning theory proposes that meaningful learning results in new and interconnected ideas and knowledge, inferring integration and then possible application of this knowledge. The ontological perspective refers to the nature or status of things in the world, the way students link their ideas and knowledge (Monk, 1995). Chinn and Brewer (1993: 17) explain it as the "students' beliefs about the fundamental categories and properties of the world."

Ontology is the description of a possible knowledge framework, designed to help understand how information is categorised in order to better understand the learning process. Information in long-term memory has some type of ontological arrangement, network and structure that does impact on understanding. This arrangement can be described as a mental schema which is central to learning (Brewer, 1999). Johnstone (1993) distinguishes the long-term memory from the working memory, emphasising that the limited size of the working memory must be considered especially when teaching chemistry because of its demands of the multiple levels of understanding as well as its new and foreign language. This implies that commonly used SI learning strategies such as breaking large ideas into small ones (through concept mapping & small group discussion); making no assumptions about previous understandings (probing questioning); identifying the processes needed to understand concepts (concept mapping and prompting questions); and providing active learning situations to correspond to students current schema (reflective practice), provide methods of handling small packets of knowledge at the working memory level before being assimilated to the long term memory (Painter, Bailey, Gilbert & Prior; 2006).

3.3.2.3. Social/ affective perspective

The social/ affective perspective refers to the socio-cultural factors of learning including the students' motivational beliefs and self-efficacious beliefs, the learning environment, the role of students in the classroom and their discursive interactions (Mortimer, 1998). This broad range of perspectives provides a useful framework in interpreting the process of conceptual change.

Conducive learning environments in which students are motivated and challenged can foster meaningful learning. According to Mannikko-Barbutiu & Sjogrund (2004), the social roles of the SI leader involve the creation of friendly and comfortable social environments in which students feel that learning is possible and therefore have the possibility of bringing about conceptual change.

It is therefore argued that students' epistemological and ontological perspectives of science and the social/ affective perspective play an important role in bringing about conceptual change. These aspects are significant in determining how the engineering students engage and get to know stoichiometry concepts in chemistry SI which is achieved through an analysis of students' engagement practices in chemistry SI.

The conceptual change process requires students to think about an idea, generate a personal mental model and evaluate it. Pintrich (1999: 42) proposes that students' self-efficacy, referring to their "confidence in their own thinking and learning strategies" and their "ability to do a particular task", should facilitate conceptual change. The process of learning is closely associated with the process of meta-cognition (Hennessey, 2003; Rickey & Stacy, 2000). This discussion concludes that developing students' awareness of their learning and developing their meta-cognitive skills may enhance their level of conceptual understanding.

3.4. Meta-cognitive theory of learning

A constructivist perspective to learning as displayed in conceptual change theory in section 3.3 above, indicates that students learn actively, evaluating new ideas through collaboration and consensus building of new conceptual understanding. Hennessey (2003: 124-126) identifies two levels of meta-cognitive thought:

- A representational level – an inner awareness of one's mental model.
- An evaluative level – an ability to draw inferences and make predictions from one's mental model.

Hennessey (2003) related the representational level to a more algorithmic level of learning and the evaluative level to an intentional level of learning. This is consistent with Skemp's (1976) model of instrumental and relational learning (Chapter Two, section 2.6.1), in which the complexity of students' schema of knowledge is reflected in their level of understanding.

Flavell (1979), described meta-cognition as thinking about thinking. More specifically, Taylor[16] (1999) defines meta-cognition as "an appreciation of what one already knows, together with a correct apprehension of the learning task and what knowledge and skills it requires, combined with the agility to make correct inferences about how to apply one's strategic knowledge to a particular situation, and to do so efficiently and reliably." McGuire[17] (undated: 2) contributes to these definitions by suggesting that meta-cognition also involves the ability to be consciously aware of ones self as a problem solver, to monitor and control one's mental processing, to recognise when one is simply memorising facts and formulas and not understanding the application of information and to know that knowledge and understanding are not handed out by an instructor but must be constructed by the student. Meta-cognition thoughts are "tied to the person's internal mental representation of reality" (Hacker, 1998:3). Therefore, the students' mental models are their meta-cognitive understanding of a concept. There are four aspects of meta-cognition, according to

[16] http://www. *academic.pgcc.edu/~wpeirce/MCCCTR/metacognition.htm*
[17] http://www.celt.lsu.edu/CFD/THE/mcguire.pdfhttp://www.celt.lsu.edu/CFD/THE/mcguire.pdf

Flavell's model of meta-cognition and cognitive monitoring as described by Hacker (1998). Students have:

a) Metacognitive knowledge – an awareness of what he/she does and does not know;
b) Metacognitive experiences – personal experiences that can be applied to his/her knowledge;
c) Goals (or tasks) – an understanding of the demands of the task;
d) Actions (or strategies) – an ability to make choices of appropriate strategies to achieve the goal.

The model above describes an active process, with conscious control of the processes by the student (Hacker, 1998). Meta-cognition is significant for this study as it is generally "thought to be a key to deeper, more durable and more transferable learning" (Rickey and Stacey, 2000: 915). They emphasise its importance firstly for chemistry teaching and learning with respect to being aware of one's own thoughts for developing an understanding of ideas and secondly, because awareness and control of thinking have been shown to have a significant impact on problem solving success, which is a key strategy used in chemistry SI.

Meta-cognition is the process of students consciously using strategies such as reflection and explanation to enhance learning in the context of chemistry SI learning (Paideya, 2010). Through learning meta-cognitive strategies, the student is learning how to learn. (McGuire, undated: 2) Davidowitz and Rollnick (2001) present data to support Flavell's assertion that there is a link between cognitive actions and meta-cognitive knowledge and experiences. They claim that "meta-cognition is a necessary pre-requisite for deep learning approaches" (Davidowitz and Rollnick, 2001:17). This position is supported by Hewson (1996:136), who claims that "teaching for conceptual change is explicitly meta-cognitive". According to Rickey & Stacey (2000), a keen awareness of students' own conceptions, whether students' knowledge is coherent or fragmented and context-bound, should allow students to recognise when their ideas are not productive or cannot be reconciled with data or ideas presented by others. Having this awareness is important during SI group discussions in developing conceptual understanding. In contrast, Sinatra and Pintrich (2003) claim that conceptual change can occur without the students' intentions, inferring that deep learning can occur with and without meta-cognition.

Maturity and knowledge has been shown to improve students' meta-cognitive ability (Bransford, Brown & Cocking, 2000). Learning through intentional conceptual change assumes that students are aware of their own learning and how they learn and this places additional responsibility onto students for the success of their own learning. The meta-cognitive process of self-regulation – "the ability to orchestrate one's own learning" (Bransford et al., 2000: 97) – can occur as early as 3-4 years of age, whereas the meta-cognitive process of self reflection – "the ability to reflect on one's own performance" (Bransford et al., 2000: 97) – appears to be late developing. According to Bransford et al. (2000), if students lack insight into their own learning abilities they cannot be expected to plan or self-regulate effectively. Therefore, meta-cognitive development is gradual and is dependent on knowledge as experience. The students' age and cognitive development may also impact on their meta-cognitive strategies.

3.4.1. Meta-cognitive Teaching Resources and Strategies

In attempting to explore students' engagement in chemistry SI, it is important to understand the effect of meta-cognitive resources and strategies in how students engage and learn stoichiometry concepts. Meta-cognitive resources can be familiar teaching resources that are used in a meta-cognitive manner such as evaluative and reflective questions and concept mapping, which are typical resources used in chemistry SI sessions. They are designed "to generate information that will help people to be knowledgeable about, aware of, and in control of what they are doing" (Baird & White, 1996: 191), thereby acting on interpretations and increasing reflection. Probing questions, reflective questions and summarising of concepts through concept mapping, are key strategies used in SI and can therefore be understood as methods of increasing students' cognitive awareness. Baird & White (1996) claim that many valuable pedagogical resources can be used in a meta-cognitive manner, when they are used in a purposeful inquiry that involves action and reflection, resulting in increased knowledge, awareness and control.

In support of the use of meta-cognitive resources and strategies, the following projects have illustrated an improvement in learning through the use of meta-cognitive resources and strategies. In a project called SMART Environments, where SMART refers to Scientific and Mathematical Arenas for Refining Thinking, Vye, Shwartz, Bransford, Barron & Zech (1998) focussed on the meta-cognitive strategies of reflection, self-assessment and revision. Through authentic problem solving environments, students were required to evaluate and choose resources upon which they obtained formative feedback. Baird and White (1996) in a Project for Enhancing Effective Learning (PEEL), observed the need for meta-cognitive development in teachers before meta-cognitive development in students. They identified four conditions necessary for the personal development of both teachers and students, viz. time, opportunity, guidance and support. Davidowitz and Rollnick (2001: 3-4) designed the Competency Tripod a device to help students describe their thoughts processes consisting of three legs – "declarative knowledge, communicative competence and procedural understanding [held together] by the link made by the students to achieve coherence of the three concepts". It is evident from these studies that meta-cognitive resources and strategies extend students meta-cognitive awareness through reflection (competency tripod), self-assessment (personal development) and revision. Similarly, Hennessey (2003) describes how explicit representations were used by students to clarify their ideas. Rickey and Stacey (2000) illustrate the instructional effectiveness of concept maps, predict-observe-explain tasks and the model-observe-reflect-explain tasks from a meta-cognitive perspective. Meta-cognitive resources and strategies therefore demonstrate an important role in the improvement of student learning and it would be interesting to note how these strategies fare in chemistry SI in improving student learning.

A meta-cognitive approach may induce a deeper level of understanding as proposed by Davidowitz and Rollnick (2001) and Hennessey (2003), who have described the success of the overt but routine use of meta-cognitive strategies in teaching and learning.

3.4.2. Importance of Meta-cognition for Chemistry Education

Studies of students' understanding of science ideas after instruction provide clear evidence that traditional didactic teaching methods are not very successful at bringing about productive changes in students' conceptions (Gabel & Samuel, 1987; Gunstone & White, 1981 and Nakhleh, 1992). Although didactic styles of instruction have been shown to be reasonably successful at imparting the facts, rules, procedures and algorithms of a domain (Anderson, 1993), they are not effective in helping students refine and build on their ideas about science concepts, partly because they neither require nor encourage high levels of student meta-cognition. However, one cannot dismiss the importance of lectures in imparting knowledge, as suggested by Anderson (1993).

At the opposite end of instructional philosophies from teacher controlled didactic teaching, is 'pure' student controlled discovery learning. Proponents of pure discovery believe that students should be encouraged to explore their environments creatively and that these explorations should not be curriculum-driven, but based on the interests of the students (Papert, 1980). However, like didactic approaches, discovery learning methods also fail to encourage student reflection. Unguided discovery learning methods in fact rely on the assumptions that students already posses advanced meta-cognitive abilities (White, 1993; Vye, Schwartz, Bransford, Barrron, Zech, Vanderbilt, 1998). These researchers assert that students in highly unstructured environments are never forced to confront their misconceptions, nor are they given the opportunity to reconcile them with scientific conceptions. In addition, pure discovery methods are seen to lack sufficient guidance and students may end up confused, not knowing what to do for long periods of time. In contrast, the goal of a supportive learning environment such as SI is to strike an appropriate balance between didactic teaching and discovery learning, allowing students to take a measure of responsibility for their own learning but also requiring them to reflect upon and explain their ideas and justify their conclusions. Science modules and in particular chemistry, also attempts to support learning through practical sessions, tutorials and assignments. These attempts are unsuccessful in most instances in developing deeper processing of knowledge because these opportunities, which are meant for collaborative engagement, are most often disseminated as individual tasks because of large class sizes, which impacts on group dynamics. This in effect reduces the probability of reflection, support and reconciliation of scientific concepts.

3.5. Conclusion

This study drew on social constructivism which could be considered at a macro level of theorising to provide ways of understanding students' engagement in chemistry SI, as SI is based on a social constructivist paradigm. Conceptual change is discussed with respect to students' epistemological and ontological perspectives of science and the social/affective perspectives which all play an important role in bringing about conceptual change and are significant in determining how the engineering students engage with and get to know stoichiometry concepts in chemistry SI. Finally, the theoretical framing with respect to meta-cognition is discussed, concluding that developing students' awareness of their learning pushes beyond student engagement and conceptual development to students taking responsibility for their learning through reflection, explanation of their ideas and justifying their conclusions in getting to know and understand chemistry, and in particular stoichiometry concepts, in this context. This study explores several learning theories in this chapter in order to understand how students' learning influences their engagement in chemistry SI.

The next chapter looks at the research design and methodology using a design research methodology to understand how SI influences student engagement in this study.

CHAPTER FOUR

RESEARCH METHODOLOGY AND DESIGN

4.1. Introduction

The previous chapter looked at the theoretical underpinnings that framed this study viz. social constructivism, conceptual theory and meta-cognition. This chapter outlines the research methodology employed in answering the critical research questions in this study:

- How does the chemistry Supplemental Instruction (SI) learning environment influence student engagement?
- How do the first year engineering students engage in the chemistry SI environment?
- Why do these engineering students engage in the way that they do?

A design research methodology is used to understand the first year engineering students' engagement within the Supplemental Instruction environment. The most compelling argument for initiating design research stems from the desire to increase the relevance of research for educational policy and practice (Van den Akker, Gravemeijer, McKenney & Nieveen, 2006). This methodology bears relevance to this study in determining how SI influences engineering students' engagement with chemistry concepts in an attempt to improve chemistry practice. Design research is relevant for this study, as both qualitative and quantitative data are produced through data generation techniques such as focus-group interviews, video recordings and individual interviews. Also, this methodology was chosen as it involved direct observation of human activity and social interaction in a natural setting.

This study is broadly located within an interpretive paradigm. Since this study is based to a greater extent on qualitative data a link is formulated between a qualitative methodology and an Interpretative paradigm; how these elements contribute to enabling design research is examined. A design research is then argued for with respect to an Interpretive approach and using a design research methodology. What constitutes design research, the inherent features of design research and how design research is used in this study, are then investigated. This involves designing chemistry SI sessions and constructing activities based on collaborative learning practices. Lastly, the data generation methods employed by this research are presented and some insight into data analysis is gained.

This chapter is divided into three main sections, research approach and design, data production plan and data analysis.

4.2. Research Approach and Design

The qualitative approach, according to Nieuwenhuis (2007), is based on a naturalistic approach that seeks to understand phenomena in context or real-world settings where the researcher does not attempt to manipulate the phenomenon of interest. Similarly, Lincoln and Guba (1985) refer to qualitative research as "naturalistic inquiry", where nothing is predefined or taken for granted. This study thus favours both a qualitative and quantitative research methodology, which generates an in-depth understanding of students' engagement within an interactive pedagogy in an attempt to answer critical questions raised.

Denzin and Lincoln (2003b) define qualitative research as a multi-method in focus, involving an interpretive, naturalistic approach to its subject matter. This means that qualitative researchers study things in their natural settings, attempting to make sense of or interpret phenomena in terms of the meanings people bring to them. This study is therefore located within the interpretive paradigm to understand how the first year engineering students engage during SI sessions using an interactive approach in the teaching and learning of stoichiometry. An interpretivist methodology, with its goal of revealing the participant's views of reality (Lather, 1992, Robottom & Hart, 1993), allowed the researcher to elicit the experiences of the participants.

Working within an interpretivist paradigm also enabled close collaboration between the researcher and SI leaders. A persistent concern in science education is the minimal impact of research on practice (Tobin, 1988). Research which involves collaboration between researcher and teacher, which focuses on an issue identified as significant by the teacher and which is carried out in the classroom, is more likely to have impact on practice (Huberman, 1993). Huberman noted the more pronounced impact of research findings on practice if the researcher-teacher relationship involves interaction over a length of time, which is evident in the iterative cycles of design research methodology used in this study.

Another reason for using an interpretivist paradigm was that it allowed for the complexities of different SI sessions to be acknowledged and explored. In addition, it had the potential to encompass and elucidate the inconsistencies and the personally subjective nature of a teaching and learning context (Eisner, 1984). An interpretivist methodology also allowed for an uncovering and description of the research context so that others may be able to connect to the findings and determine the correspondence of such to their own context.

This research explores improvement in educational practices, in light of students' engagement in interactive SI sessions, to develop insights into Chemistry teaching and learning using a design research methodology. Design research is a fairly new research methodology in education (Edelson, 2002; Barab & Squire, 2004; Bell, Hoadley & Linn, 2004; Hoadley, 2004, 2005; Kelly; O'Donnell, 2004; Sandoval & Bell, 2004; Wang & Hannafin, 2004; Smith & Ragan, 2005). According to Gravemeijer & Cobb (2006), a key element in design research is the ongoing process of experimentation in the interpretation of both the students' reasoning and learning and the means through which that learning is supported and organised. Design researchers employ an interpretive framework to make sense of the complexity and messiness of classroom events, while a design experiment is in progress as well as when conducting a retrospective analysis of the data generated during an experiment.

Key elements of such an interpretative paradigm include: (1) a framework for interpreting the evolving SI learning environment, and 2) a framework for interpreting student stoichiometry reasoning and learning. These interpretative frameworks were analysed within a case study approach.

A case-study approach (Denscombe, 1998; Cohen, Manion, & Morrison, 2000) was selected as the research methodology. The case study focuses on one or several instances of a particular phenomenon with a view to providing an in-depth account of the events, relationships, experiences, or processes involved (Denscombe, 1998). This study is considered a case study because it is located at a particular institution, UKZN, and focuses on a specific cohort of students (first year engineering students) as well as a particular group of SI leaders. According to Best and Kahn (2003), a case study probes deeply and analyses interactions between the factors that explain present status or that influence change or growth.

This study focuses on natural settings within chemistry classrooms, and it allowed for the use of multiple sources and multiple research methods, such as video-recordings, observations, focus group interviews, SI leader reflective journals and concept maps. According to Cohen, Manion & Morrison (2007: 253), the possible advantages of case studies are a "study of an instance in action". They begin in a world of action and contribute to it. Their insights may be directly interpreted and put to use for staff or individual self-development, for institutional feedback or for formative evaluation. It is hoped that these insights will be beneficial to the development of the institution, in essentially assessing the effectiveness of supplemental instruction as an interactive pedagogical method to improve the quality of chemistry teaching and learning. According to Nieuwenhuis (2007), the typical characteristic of case studies from an Interpretive perspective is that they strive towards a comprehensive (holistic) understanding of how participants make meaning of a phenomenon under study, which in this case was engineering students' engagement in SI sessions.

4.2.1. Design Research Methodology

Wang & Hannafin (2004: 2) define research design as "a research methodology aimed to improve educational practices through systematic, flexible and iterative review, analysis, design, development and implementation, based upon collaboration among researchers and practitioners in real-world settings, and leading to design principles or theories."

This study may be categorised as falling within the broader category of design research that aims at creating innovative learning ecologies in order to develop local instruction theories, on the one hand, and to study the forms of learning that those learning ecologies are intended to support on the other (Atkinson, Delamont and Hammersley, 1988). This locates it in design research. Gravemeijer & Cobb (2006) documented an analytical approach used to develop accounts of middle school (12-14 year old students) students' mathematical learning as it occurred in the social context of the classroom which emerged over a 12 year period. They conducted a series of teaching experiments which were up to a year in duration; in the study, they developed sequences of instructional activities and analysed both students' mathematical learning and the means used to support that learning. They argue that research of this type falls under the general heading of design research in that it involves both instructional design and classroom-based research.

According to Gravemeijer & Cobb (2006:17), "the underlying philosophy of design research is that you have to understand the innovative forms of education that you might want to bring about in order to be able to produce them". They claim that this fits with the adage "if you want to change something you have to understand it and if you want to understand something you have to change it" (Gravemeijer & Cobb, 2006: 17). These notions have been influenced by the two authors' histories and practice, where the socio-constructivist approach was inspired by a desire for understanding (Cobb) and realistic mathematics education (RME) by the need for educational change. The second part of the adage will only be discussed in light of the fact that this study is based on a socio-constructivist theoretical framework and thus explains the link between social constructivism and the design research framework.

The second part of the adage calls for understanding and it should be noted that the notion of design research has been around for a long time although design research is regarded as a fairly new research methodology, where various forms of professional instructional design may be perceived as informal predecessors of design research. Gravemeijer & Cobb (2006: 17) argue that "the recognition that instructional design often had an innovative character, while the available scientific knowledge base was far too limited to ground the design work which sparked the idea for a type of instructional design that integrated design and research".

Gravemeijer & Cobb (2006: 18) also claim that the second part of the adage, "if you want to understand something you have to change it", points to the other predecessor of their collaborative work on design research, the constructivist "teaching experiment methodology". In this methodology, one-to-one teaching experiments focused primarily on understanding how students learn rather than on educational change. According to Gravemeijer & Cobb (2006: 18), "the need for classroom teaching experiments arose when analysis of traditional instruction within the socio-constructivist research program produced only negative advice for the teachers, advice of the type: "*Don't do this and don't do that".* It was envisaged that one of the ways to create more productive classroom environments, was for researchers to take responsibility for the design of classroom instruction for an extended period of time. The one-to-one teaching experiment methodology was expanded to classroom teaching experiments.

Gravemeijer & Cobb (2006), claim that the goal of design research is very different from experimental or quasi-experimental research in that different goals imply different methods and different forms of justification. In relation to this, they quote the NCTM Research Advisory Committee (1996) that observed a shift in norms of justification in mathematical education research. The committee argued that this was a shift from research that proves that treatment B works better than treatment A, towards research that provides an *empirically grounded theory on how the* *intervention works* as it goals. It should be noted that the intended result of this type of research is theory. The purpose therefore of design experiments is to develop theories about the process of learning and the means designed to support that learning. Gravemeijer & Cobb (2006) state that one may work towards this goal in two ways, either by developing local instruction theories, or by developing theoretical frameworks that address more encompassing issues.

Design research methods focus on designing and exploring a range of designed innovations-artefacts as well as activity structures, institutions, scaffolds, curricula and particular interventions (Design-based Research Collective, 2003). It is an emerging paradigm for studying strategies and tools to support learning in practice. The aim of this research methodology is to understand not only the design solution but the design process. Therefore in this study, the design and research processes are integrated with the design research methodology.

Design research has many advantages in that it speaks directly to problems of practice and produces directly applicable solutions; that is, it leads to development of "usable knowledge" (Lagemann, 2002: pg). It also helps to understand relationships among educational theory, designed artefacts, and practice. It advances theories of learning and teaching in complex settings, and creates conditions for inquiring about unique educational phenomena (Juuti, 2005). In contrast, action research methodology maps out an explicit, cyclical evaluation process that enables stakeholders, including teaching staff and students, to reflect on and make ongoing improvements to teaching and student learning through empowerment and skills development of participants to effect change in their environment (Sarantakos, 2005). Design research methodology differs from action research methodology in that design-based reach aims to assist, create and extend knowledge about developing, enacting and sustaining innovative learning environments (Kelly, 2003). Further, design research theorises the methodology during the iterative cycles of innovation and accounts more adequately for the systematic iterative nature of activities, program evaluation processes, decision making and growth of the initiative (Sharma & McShane, 2008). Design-based research blends empirical educational research with theories of learning and the design of learning and as such is "an important methodology for understanding how, when and why educational innovations work in practice" (The Design-Based Research Collective, 2003: 5). It is the intent of this study to produce an empirically grounded theory on how the innovation works in understanding how engineering students engage and learn stoichiometry concepts in SI; hence a design research method was adopted.

Design research usually includes different stages, each having different goals (Cobb, 2001). The process of design is essentially iterative: it includes cycles of innovations and revision (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003). It usually triangulates multiple sources and kinds of data (Design-Based Collective, 2003) to understand the features of an implemented innovation. This study follows three different stages, viz. the *design phase*, *implementation phase* and *reflective phase*. The *design phase* involves designing the SI learning environment; the *implementation phase* involves engaging the engineering students with stoichiometry concepts in chemistry, and the *reflective phase* involves establishing why the engineering students engage in the way that they do. For the purposes of this study, data were only collected from the *implementation* and *reflective phases*. Iterations were made during the *implementation phase* and *reflective phases* which involved cycles of innovation and revision by SI leaders during student engagement with stoichiometry concepts. Multiple data sources such as observations, video recordings, SI leaders' reflective journals, focus group interviews and individual interviews were used which allowed for triangulation of data.

4.2.2. Inherent features of Design research

Design experiments bring together two critical pieces in order to guide us to better educational refinement through a design focus and assessment of critical design elements (Collins, Joseph & Bielaczyc, 2004). Cobb, Confrey, diSessa, Lehrer & Schauble (2003) have identified five cross-cutting features that apply to design experiments. Firstly, they emphasise that the purpose of design experimentation is to develop a class of theories about both the process of learning and the means that are designed to support that learning. In the case of a one-on-one design experiment (teacher experimenter and student), for example in this study, it is proposed that the broader theoretical goal might be to develop a psychological model of the process by which students develop a deeper understanding of chemistry concepts, together with the type of tasks and SI leader practices that can support that learning. The theoretical goal might be to develop an interpretive framework that explicates the relations between SI leaders' instructional practices and the institutional settings in which SI leaders develop and refine their practices. In these and other design experiments, the initial design formulated when preparing for an experiment and the new form of learning it is designed to support, are viewed as instances of broader classes of phenomena, thereby opening them to theoretical analysis.

The second feature the authors mention is the highly interventionist nature of the methodology. The intent of design studies is to investigate the possibilities for educational improvement by bringing about new forms of learning in order to study them. It is emphasised that the use of prior research to both specify a design and justify the differentiation of central and ancillary conditions is central to the methodology. For example, in a study of students' chemistry development, classroom norms of justification might be assumed as background to the study and the emphasis placed instead on conceptual development.

The third feature states that design experiments create the conditions for developing theories and testing these theories. Thus, design experiments always have two faces, the prospective and reflective. On the prospective side, designs are implemented with a hypothesized learning process and the means of supporting it in mind in order to expose the details of that process to scrutiny. On the reflective side, design experiments are conjecture-driven tests often at several levels of analysis. The initial design is suggested to be a conjecture about the means of supporting a particular form of learning that is to be tested. This is evident in SI sessions were different pedagogical strategies are conjectured and modified in an attempt to develop a collaborative and engaging SI environment.

Together, the prospective and reflective aspects of design experiments result in the fourth characteristic, iterative design. As conjectures are generated and perhaps refuted, new conjectures are developed and subjected to test. The result is an iterative design process featuring cycles of invention and revision. SI lends itself to design research in that SI leaders are required to reflect upon each SI session as part of the SI methodology in establishing which pedagogical activities are fruitful in developing understanding and engagement with chemistry concepts (in this case), and which are not. Further, SI leaders are required to develop new conjectures to be tested and modified on a weekly basis with respect to each and every SI session.

The fifth feature of design experimentation reflects its pragmatic roots. These are theories developed during the process of experimentation and are not only concerned with domain-specific learning processes, but also because they are accountable to the activity of design. This also held true for chemistry SI in that the process of adapting and revising conjectures with respect to chemistry learning, was informed by an ongoing analysis of SI session events.

The chemistry SI sessions conducted during the design experiment were organised so that students initially work either individually or in small groups before convening for a whole-class discussion of their solutions. SI encourages a facilitated learning experience. Hence a pedagogical strategy that involves the SI leader circulating around the classroom during individual or small group discussions in order to gain a sense of the diverse ways in which students are interpreting and solving instructional activities, was used. The whole-class discussion followed, where SI leaders developed conjectures about chemistry significant issues that emerged as topics of conversation with the SI leaders' guidance and support. The intention was to capitalise on the diversity in students' reasoning by identifying interpretations and solutions that, when compared and contrasted, would lead to substantive chemistry discussion. It is therefore evident that SI lends itself to design research in its pragmatic focus on developing individual students' reasoning through illative cycles of conjectures and modification.

4.2.3. Design research in this study

This theory-driven approach is illuminative: includes all stakeholders' perspectives and provides methods to interpret findings in light of contextual factors (Wang & Hannafin, 2005:9). It also aims to provide guidance for application of the educational principles and designs involved in this study to contexts beyond the development of the SI environment.

In understanding design research in this study, the three phases of conducting a design experiment are discussed, viz. preparing for the experiment, experimenting in the classroom and conducting retrospective analyses. Gravemeijer & Cobb (2006) suggest that from a design perspective, the goal of the preliminary phase of a design research experiment is to formulate a local instruction theory that can be elaborated and refined while conducting the experiment. From a research perspective, it is believed that a crucial issue is that of clarifying the study's theoretical intent. The local instruction theory encompasses both provisional instructional activities and a conjectured learning process that anticipates how students' thinking and understanding might evolve when the instructional activities are employed in the classroom.

It should be noted that although this study focuses on engineering students, SI leaders play a fundamental role in understanding how an interactive teaching and learning program, viz. Supplemental Instruction, can be used to engage first year engineering students in quality chemistry teaching and learning. The iterative process as well as the different phases of the design research methodology used in this study served as a fundamental feature in developing and understanding the role of the SI leader in creating discursive learning spaces for student engagement within the Supplemental Instruction environment.

Design research in this study has three main phases:

- Phase 1: Designing and developing the learning environment related to the goals of SI.

- Phase 2: Implementation of the innovation - taking into account students' views and their assessed learning outcomes within the environment.
- Phase 3: Assessing the effectiveness of the intervention's influence on students' knowing in stoichiometry through retrospective analysis.

4.2.3.1. Phase One

The preparation for a design experiment typically begins with the clarification of the chemistry and in particular the stoichiometry learning goals. According to Gravemeijer & Cobb (2006), such clarification is needed, as one cannot simply adopt the educational goals that are current in a given domain. These goals in practice are largely determined by history, tradition and assessment practices. It is therefore believed that the design researcher cannot take these goals as a given when starting a design experiment. Instead, researchers need to problematise the topic under consideration from a disciplinary perspective and ask themselves: What are the core ideas in this domain? They state that this elaboration serves to emphasise that the goal of design research is not to take the currently instituted or institutionalised curriculum as a given, but to rather find better ways to achieve the already defined goals. In the case of this study, students' learning engagement with stoichiometry concepts was problematised to determine the learning goals for stoichiometry.

Gravemeijer & Cobb (2006) further add that in order to be able to develop a conjectured local instruction theory, one also has to consider the instructional starting points to understand the consequences of earlier instruction. This is done not merely to document the typical level of reasoning of the engineering students with stoichiometry concepts in this study, but rather to establish existing research literature, psychological studies and prior assessment such as whole class assessments and interviews done by the researcher. The literature discussed in Chapter Three has revealed that students have many difficulties with stoichiometry concepts because they lack prior mathematical skills as well as abstract reasoning skills. Psychological studies can usually be interpreted as documenting the effects of prior instructional history, and to complement such a literature study, the researcher is required to carry out their own assessments as in the case of this study. A baseline study was therefore conducted before starting the design experiment, where it was established that students preferred more interactive or collaborative means of studying stoichiometry concepts. Thus the conjectured local instruction theory that was developed focussed on the assumption that engineering students abstract reasoning skills needed to be developed through collaborative discussion, in order to succeed with stoichiometry concepts.

In preparation for the design experiment, students' prior knowledge with respect to stoichiometry concepts was established through the use of probing questions by the SI leader. "These performance assessments clearly revealed the consequences of the students' prior instruction" (Gravemeijer & Cobb, 2006: 20). It has been established by Gravemeijer & Cobb (2006) that design researchers also have to consider the nature of classroom norms and classroom discourse in preparation for design experiments. They assert that one cannot plan interactional activities without considering how they are going to be enacted in the classroom. In this study, the SI classroom norms and discourse were guided by SI methodology, which involved peer and group discussions, students' explanation of concepts and whole class discussions. SI leaders were trained to developed classroom norms with respect to group and peer discussions; students' explanations of concepts on the chalkboard had to be explained to the class and the rest of the SI group were allowed to ask questions with respect to the solutions. The training of SI leaders' also involved establishing group discussion norms around the SI group reaching consensus with the different explanations offered during discussions.

Besides elaborating on a preliminary instructional design, Gravemeijer & Cobb (2006) claim that the theoretical intent of the design experiment also needs to be formulated, because the goal of a design experiment is not just to describe what happened in a particular classroom. They suggest that one of the primary aims of a design experiment is to support the constitution of an empirically grounded local instruction theory. Another aim of a design experiment might be to place classroom events in a broader context by framing them as instances of more encompassing issues. In this study, analyses that focused on the proactive role of the SI leader in modelling or more generally, of semiotic processes in supporting students' learning engagement, is the explicit focus of the investigation.

A third type of theory described by Gravemeijer & Cobb (2006) that could emerge during a series of design experiments are theories or theoretical frameworks that entail new scientific categories that can do useful work in generating, selecting and assessing design alternatives. These new frameworks often emerge from design experiments in answer to the need to understand surprising observations. The frameworks are referred to as ontological innovations that can serve as lenses for making sense of what is happening in the complex, more-or-less real world instructional setting, in which a design study is conducted and which functions as a guideline or heuristic for instructional design. The concepts of establishment of social norms which will be discussed later in this chapter may function as an example of an ontological innovation. The concepts may offer an interpretative framework for analysing SI group discourse and communication.

4.2.3.2. Phase Two

The second phase entails conducting the design experiment. Gravemeijer & Cobb (2006), state that the objective of the design experiment is not to try to demonstrate that the initial design or local instruction theory work. Instead, the purpose of design experiment is both to test and improve the conjectured local instruction theory that was developed in the preliminary phase, and to develop an understanding of how it works.

At the heart of design experiment lies a cyclic process of (re)designing and testing instructional activities and other aspects of the design. In each lesson cycle, the research team (SI leaders and researcher) conducted an anticipatory thought experiment by envisioning how the proposed instructional activities might be realised in interaction in the classroom and what the engineering students might learn as they participated in them. During the enactment of the instructional activities in the classroom and in retrospect, the research team tried to analyse the actual process of student participation and learning in the SI learning environment. On the basis of this analysis, the research team made decisions about the validity of the conjectures that were embodied in the instructional activity, the establishment of particular norms, and the revision of these specific aspects of the design. The design experiment therefore consists of cyclic processes of thought experiments and instruction experiments (Freudenthal, 1991: Figure 4.1) as cited in Gravemeijer & Cobb (2006:25).

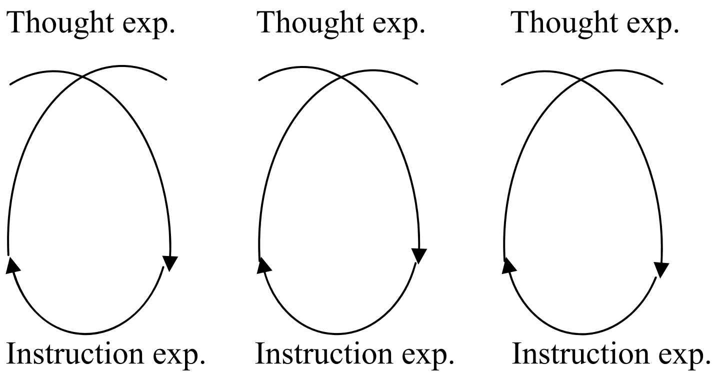

Figure 4.1: Developmental research, a cumulative cyclic process

These micro-cycles of design and analysis may be associated with Simon's (1995) "mathematical teaching cycle". According to this idea, the teacher (in this case the SI leader and researcher) first tries to anticipate what the mental activities of the students will be when they participate in some envisioned instructional activities. The teacher (or SI leader and researcher) then tries to find out to what extent the actual thinking processes of the students corresponded with the hypothesized ones during the enactment of those activities, to finally reconsider potential or revised follow-up activities. Simon coined the term "hypothetical learning trajectory" to characterise the teachers thinking which he described as "the consideration of the learning goal, the learning activities and the thinking and learning in which the students might engage" (Simon, 1995: 133). The mathematical teaching cycle then may be described as conjecturing, enacting and revising hypothetical learning trajectories.

According to Gravemeijer & Cobb (2006), the micro-cycles of design and analysis may be compared with the concept of an empirical cycle of hypotheses testing. The goal of the design researcher is not just to find out whether the participation of the students in particular activities results in certain anticipated behaviours, but to understand the relation between the students' participation and the conjectured mental activities. Therefore in this study the micro-cycles of design and analysis involved inferences about both the mental activities and observable behaviour of the engineering student in developing an understanding of stoichiometry concepts.

Gravemeijer & Cobb (2006), add that in a design experiment, the micro-cycles of thought and instruction experiments serve the development of the local instruction theory. They suggest that there is a reflexive relation between the thought and instruction experiments and the local instruction theory that is being developed. On the one hand, the conjectured local instruction theory guides the thought and instruction experiments and on the other, the micro-cycles of design and analysis shape the local instruction theory (Figure 4.2).

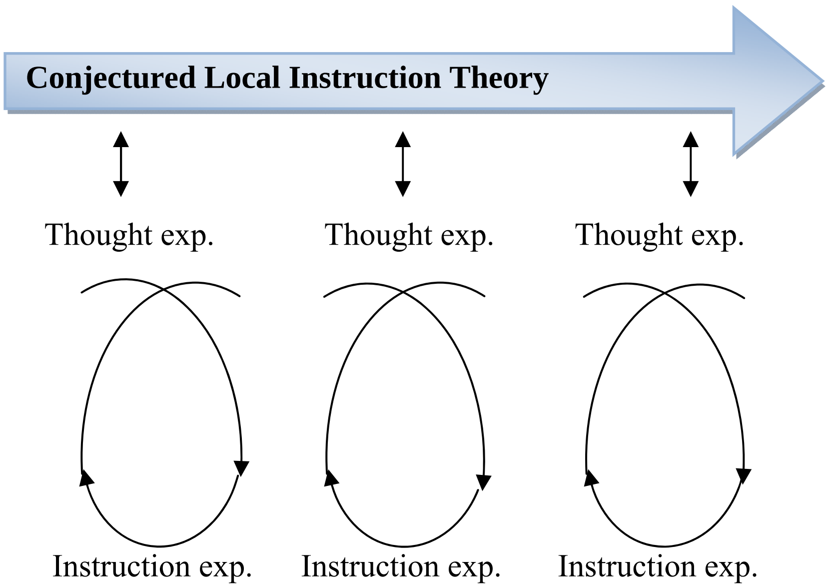

Figure 4.2: Reflexive relationship between theory and experiments

These micro-cycles therefore required that the research team in this study engage in an ongoing analysis of students' activity and of SI classroom social processes to inform new anticipatory thought experiments, the design or revision of instructional activities and sometimes, the modification of learning goals. This analysis process involved the researcher conducting short debriefing sessions with the SI leader immediately after each SI session in order to develop shared interpretations of what might be going on in the SI sessions.

According to Gravemeijer & Cobb (2006), it is also vital to engage in longer period meetings that focus on the conjectured local instruction theory as a whole. These longer meetings were conducted at least once a week between SI leaders and the researcher and primarily focused on the conjectured local instructional theory of how students engage with stoichiometry concepts in chemistry SI. Gravemeijer & Cobb (2006) claim that a local instruction theory encompasses both the overall process of learning and the instructional activities that are designed to foster the mental activities that constituted the long-term process. So, a process of conjecturing and revising (known as retrospective analysis) may be observed on two levels, on the level of the individual SI sessions and on the level of the instructional sequence as a whole. In addition to the adaptation of the overall learning process during a design experiment, macro-cycles may also be discerned, which span entire experiments, in the sense that the retrospective analysis of a design experiment can feed forward to inform a subsequent experiment (Figure 4.3). Gravemeijer & Cobb (2006) claim that from this process emerges a more robust local instructional theory that is still revisable.

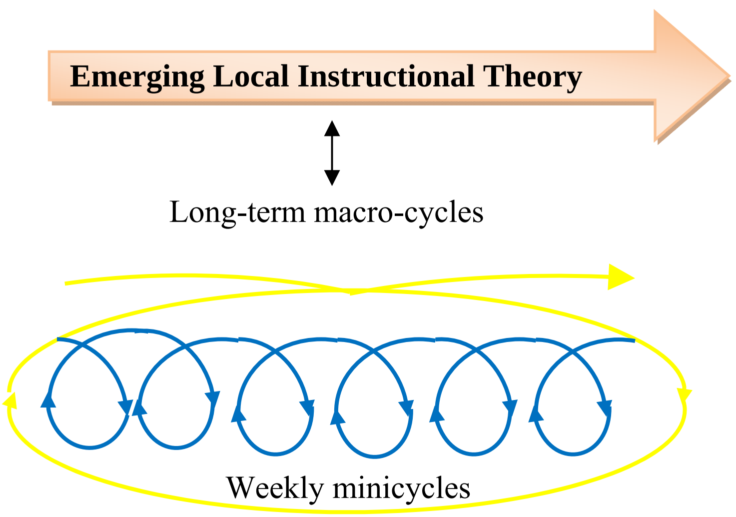

Figure 4.3: Micro and macro-design cycles

Phase three of the design experiment is then considered in preparation of the data set for first level analysis.

4.2.3.3. Phase Three

Thus far the planning of a design experiment and the ongoing experimentation in the chemistry SI sessions has been discussed. A further aspect to design research methodology concerns retrospective analyses that are conducted of the entire data set collected during the design experiment. Gravemeijer & Cobb (2006) suggest that the goal of the retrospective analyses will depend on the theoretical intent of the design experiment which in this study is to establish how engineering students engage in chemistry SI to develop their mathematical and abstract reasoning skills required for stoichiometry learning. However, one of the primary aims is typically to contribute to the development of a local instruction theory. Other goals may concern more encompassing issues or ontological innovations. They suggest that although differences in theoretical objectives are reflected in differences in the retrospective analyses, the form of analysis involves an iterative process of analysing the entire data set.

The data sets in this study include videotapes of all chemistry SI sessions, transcripts of individual and focus group interviews and SI leader reflective journal entries. The challenge was to analyse this comprehensive data set systematically while simultaneously documenting the grounds for particular inferences. Claims are based on a retrospective systematic and thorough analysis of the entire data set collected during the experiment. Gravemeijer & Cobb (2006) suggest that to ascertain the credibility of the analysis, all phases of the analysis process have to be documented, including the refining and refuting of conjectures. Final claims and assertions can then be justified by backtracking through the various levels of the analysis if necessary. It is this documentation of the students learning process that provides an empirical grounding for analysis. The instructional sequence is put together by focussing on and reconstructing the instructional activities that constitute the effective elements of the sequence. This reconstruction of an optimal sequence is based on the observations and inferences made during the design experiment, complemented by the insights gained when the results of a design experiment are empirically grounded.

In this cycle, the conjectures and assumptions formulated at the outset when planning a design experiment are scrutinised in the retrospective analysis.

4.2.3.4. Ecological Validity

According to Gravemeijer & Cobb (2006), design research aims for ecological validity. That is to say, the description of the results should provide a basis for adaptations to other situations. The premise is that an empirically grounded theory of how the intervention works accommodates this requirement. Therefore, Gravemeijer & Cobb (2006: 45) claim that "one of the primary aims of this type of research is not to develop the instructional sequence as such but to support the constitution of an empirically grounded local instruction that underpins that instructional sequence".

The intent is to develop a local instruction theory that can function as a frame of reference for educators who want to adopt the corresponding instructional sequence to their own SI sessions and their personal objectives of stoichiometry learning. Gravemeijer & Cobb (2006) suggest that one element that can be helpful in this respect is offering a thick description of what happened in the design experiment. They contend that a description of details of the teaching and learning process, together with an analysis of how these elements may have influenced the whole process, will have a basis for deliberating adjustments to other situations. It is further suggested that feedback from the SI leaders' reflective journals, for example on how the instructional sequence was adjusted to accommodate various SI classrooms, can strengthen the ecological validity significantly.

4.2.4. Research Context

This study has explored how students experience stoichiometry in terms of chemical reactions (stoichiometry), as this section poses many problems to the students at first year level at UKZN. Evidence of the difficulties students have experienced with stoichiometry has been revealed in poor test and examination results as well as anecdotal staff meeting discussions. Stoichiometry is one of the most basic, yet abstract topics in chemistry and seems to be an international problem with most students (as indicated by BouJaoude & Barakat, 2003 and Agung & Schwartz, 2007, discussed in Chapter Two, Section B of this study). Considerable abstract thinking skills in chemistry are needed to build an understanding of ideas of chemical reactions and in particular stoichiometry. Results from BouJaoude & Barakat's (2003) study of students' problem-solving strategies in stoichiometry revealed that most students resorted to algorithmic problem-solving, which may be viewed as a safe and sure way to the correct answer, even when they did not have adequate understanding of the relevant concepts. Therefore as a methodological consideration with respect to stoichiometry teaching and learning, SI pedagogical methods were used to develop higher order thinking skills according to Blooms taxonomy[18] and a better understanding of stoichiometry concepts.

The following sections within stoichiometry were explored during the observation of 15 SI sessions: molecular mass, percentage composition, empirical formulae, limiting reagents and reaction yield. These subsections represent mass relationships in chemical reactions and examine the quantities of substances consumed and produced in chemical reactions. Research discussed in Chapter Three by BouJaoude and Barakat (2000); Furio, Azcona and Guisasola (2002); Fach, Boer and Parchmann (2007) indicates that students require a deep understanding of the mole concept, chemical formulas and the law of conservation of mass. BouJaoude & Barakat (2003) assert that there are major misunderstandings of molar quantities, limiting reagents, conservation of matter, and molar volume of gases at STP. Students also need to acquire higher order thinking skills in order to apply analyse and synthesise information in attempting to answer questions based on stoichiometry. It would therefore be interesting to note whether the interactive strategies offered by SI show any significant improvement in students' understanding of stoichiometry concepts.

[18] This taxonomy of the cognitive domain, developed by Bloom and colleagues, defines a hierarchy of six levels of cognitive function. The original taxonomy specified Knowledge as the lowest level, and Evaluation as the highest level. Knowledge, Comprehension and Application are lower order functions and Analysis, Synthesis and Evaluation are higher order functions. This taxonomy was updated by Anderson (1991), to Remembering, Understanding and Applying as lower-order levels and Analysing, Evaluating and Creating as higher-order levels.

In this study, supporting knowing in chemistry required the implementation of appropriate pedagogical strategies within the learning environment, such as inquiry-based instruction within collaborative learning groups using probing questions, concept mapping and paired problem-solving. According to the assumptions proposed by SI, probing questions were believed to assist students begin to process information beyond the superficial level of delivering the 'right' answer. This was assumed to happen when students begin to genuinely interact with the material by clarification, critical thinking, explaining it in their own words and relating it to other knowledge (Nelson Mandela Metropolitan University, 2008).

Graphic organisers, such as concept maps, were suggested as a way to organise information and thoughts for better understanding. They help students link new information to their knowledge schema and promote interaction among students (Trowbridge & Wandersee, 1998). Concept maps were used by SI leaders to assess students' understanding of stoichiometry concepts. Paired problem solving in contrast, is a procedure, which is designed to capitalise on meta-cognitive learning, or the ability to clarify one's thinking by explaining a concept or a procedure to another. Probing questions, concept mapping and paired problem-solving are some of the different pedagogical strategies used to support deep understanding (Leithwood et al., 2006).

In this study, it is assumed that inquiry-based learning within an SI environment using appropriate pedagogical strategies can influence students' knowing within the SI learning environment. This study takes the form of small group discussions (consisting of between 8-10 students) in chemistry SI sessions, where students were encouraged to use higher-order thinking skills by clarifying task objectives, devising a plan of action, analysing the results, evaluating their results by presenting their results to other students and constructing a concept map of phenomena where appropriate.

4.3. Data Generation Plan

Qualitative research is generally based on non-probability and purposive sampling rather than probability or random sampling approaches. Purposive sampling simply means that participants are selected because of some defining characteristic that makes them the producers of the data needed for the study (Nieuwenhuis, 2007). In this study, a purposive and an 'opportunistic' sample population of students attending SI sessions were chosen. Engineering students were purposively selected for the focus group and individual interviews as regular attendees to chemistry SI sessions. This sample of SI attendees was regarded as a homogenous group of students since their average grades in Mathematics and Physical science for NCS examinations was above 70% as mentioned earlier. Two SI groups from the Chemistry for engineering modules were analysed over a period of 13 weeks (two university terms or one semester). Data generation with respect to design experiments involves keeping a log of the ongoing interpretations, conjectures and decisions made during experimentation.

In an attempt to build internal validity and ensure the credibility of the findings, the data production plan triangulated the data in three ways viz. method, source and form. This triangulation is summarised in the table below:

Table 4.1: Research methods used in attempting to answer critical questions

METHOD	SOURCE	FORM
Observation over ***13 week*** *period*	Engineering students and SI Leaders	Observation schedule Field notes, video footage
SI Leader Reflective Journal Entries (***15 entries***)	SI Leaders	Video footage of student and SI Leader engagement
Focus Group Interviews One focus group interview with each of the ***two*** engineering groups	Engineering students	Transcripts of focus group interviews
Individual Interviews (7) Students from three different ability groups were interviewed once with respect to their experiences of SI	Engineering students	Transcripts of individual interviews

The qualitative research methods employed in the study were observations, focus group interviews, individual student interviews and SI leader reflective journal entries. Observations in the chemistry SI sessions have been the main data-gathering method related to the research questions of this study (refer to table above).

According to Gravemeijer & Cobb (2006), the theoretical intent of the design experiment influences the type of data that needs to be generated in the course of an experiment. It is emphasised that if the design experiment focuses on the development of a local instruction as in this study, then it makes sense to video record all SI sessions, conduct pre- and post- interviews with the engineering students, make copies of students' work and assemble field notes. Data generation therefore involved keeping a log of the ongoing interpretations, conjectures and decisions.

A key element in the ongoing process of experimentation is the interpretation of both the engineering students' reasoning and learning of stoichiometry concepts in this study and the means by which that learning is supported and organised (Gravemeijer & Cobb, 2006). An emergent perspective (Cobb & Yackel, 1996) was used to interpret SI classroom discourse and communication and a conceptual framework was used to interpret student learning, as discussed in Chapter Three. In doing so, it is clarified that socio-constructivism functions as a background theory in this study. This framework adapted from Gravemeijer & Cobb (2006), is used as a response to the issue of attempting to understand chemistry learning as it occurs in the social context of the SI sessions.

Social Perspectives	**Psychological Perspectives**
SI social norms	Belief about SI leaders/ students' role, others' roles, and the general nature of chemistry activity
Socio-scientific norms	Specific scientific beliefs and values
SI chemistry practices	Chemistry conceptions and activity

Table 4.2: An interpretive framework for analysing individual and collective activity at the SI classroom level

In Table 4.2, the column headings *Social Perspectives and Psychological Perspectives* involve a focus on the SI community and on the individual students' reasoning, respectively. With reference to *social norms, socio-scientific norms* and finally *SI chemistry practices* are discussed using Gravemeijer & Cobb's (2006) framings of these concepts as follows:

Social norms refer to expected ways of acting and explaining that became established through a process of mutual negotiation between the SI leader and the engineering students. In SI whole class discussions, students were obligated to explain and justify solutions (through SI leaders' probing, prompting and redirecting questions); attempt to make sense of explanations given by others; indicate agreement and disagreement, and question alternatives in situations where a conflict in interpretation or solution was apparent.

The psychological correlate to social norms concerned the SI leader and students' individual beliefs about their own and others' roles. The reflexivity between social norms and individual beliefs was better understood when analysing the negotiation process of the SI community. It was suggested by Gravemeijer & Cobb (2006), that on the one hand, a student's beliefs were enabled and constrained as he or she participated in this negotiation process, and on the other hand, a student's beliefs are enabled and constrained as he or she participates in this negation process.

The *socio-scientific norms* can be distinguished from social norms as ways of explicating and acting in SI whole class discussions that are specific to chemistry and science. Examples of such socio-scientific norms included what counted as different chemistry solutions, a sophisticated chemistry solution, an efficient chemistry solution and an acceptable chemistry explanation and justification. The students' personal beliefs about what made a contribution acceptable, different, sophisticated or efficient encompass the psychological correlate of the socio-scientific norms. Students developed personal ways of judging whether a solution was efficient or different, and these beliefs were mutually negotiated as the SI micro-culture was continually being structured. That is, the SI leader did not merely state specific guidelines for what types of solutions were acceptable and expect the guidelines to be understood and enacted by students. Instead, socio-scientific norms were continually negotiated and refined using SI learning principles of feedback, reflection and peer collaboration as the SI leader and students participated in discussion.

According to Gravemeijer & Cobb (2006), the analysis of socio-scientific norms has proved to be pragmatically significant when conducting design experiments in that it clarifies the process by which SI leaders may foster the development of intellectual autonomy in SI sessions. To create the opportunity for the students to take over the SI leader's responsibility as validators, socio-scientific norms that enable students to make independent judgements that contribute to the SI leader's teaching agenda need to be in place.

The last social aspect concerns *chemistry practices* that were established in the SI classroom (Cobb, Stephan, McClain & Gravemeijer, 2001). A chemistry practice can be described as the normative ways of acting, communicating and symbolising chemistry at a given moment in time. In contrast to socio-scientific norms that are specific to science, chemistry practices are specific to particular chemistry ideas or concepts. In addition, chemistry practices evolve in the course of an experiment whereas socio-scientific norms tend to be more stable.

An indication that a certain chemistry practice has been established is that explanations pertaining to it have gone beyond justification. Individual students' chemistry interpretations and actions constitute the psychological correlates of chemistry practices in SI. Their interpretations and the chemistry practices are reflexively related, as students' chemistry development occurs as they contribute to the constitution of chemistry practices. Gravemeijer & Cobb (2006) conclude by noting that in the context of a design experiment, a detailed analysis of evolving SI practices offers a way of describing the actual learning process of the SI learning community as a whole. This offers a viable alternative for describing the learning process of the SI classroom rather than implying that all engineering students are learning in unison, or attempting to describe the learning processes of each individual student.

The researchers' role as teaching and learning manager in the Supplemental Instruction Programme allowed for first-hand observation of chemistry SI sessions. Students were accustomed to the researchers' presence at the chemistry SI sessions; however, they had to initially get accustomed to the presence of a video camera. Observations were recorded through video-recordings of SI sessions and an observation schedule for each of the SI sessions. Supplemental Instruction (SI) has been explored in this study for its effectiveness in engaging engineering students with stoichiometry concepts in an attempt to improve the quality of chemistry learning. The use of a mixed methodology and the research instruments enabled the researcher to become immersed in a social setting. A relationship of trust and respect was developed with the SI leaders and first year engineering students.

4.3.1. Observations

The use of video-recordings helped to observe situations more than once. In particular, students' social discourse in small groups served as indicators of meaningful chemistry learning. Students' dialogue was assessed for higher-order thinking and deeper understanding, by examining students' scientific reasoning with interactive protocols (Hogan and Fisherkeller, 2000). There are various ways to assess higher-order thinking in the literature, one being open-ended assessment (Zohar, 2004). Open-ended questions and probing questions have been used to assist the researcher and the SI leaders to understand more clearly how the engineering students think, what the prior knowledge of students is, and what understandings students gained during group discussion and oral presentation. Video data were transcribed by the SI leaders immediately after each SI session to ensure the reliability of the data as well as to facilitate the development of new conjectures for the design experiment.

There were two observers (the researcher and the SI leader) for each session, to observe students' engagement in the learning environment. SI leaders' observations were recorded in their reflective journals. Observation schedules were used to assist in answering the research questions, and also allowed for comparison with the reflective journals of the SI leaders. This strategy was used to inform the quality of teaching and learning engagements.

4.3.2. SI Leader Reflective Journals

SI leaders were asked to reflect on all fifteen SI sessions observed which constituted part of the iterative cycles of the design research methodology. Murray (1999) regards the SI leaders' role as very challenging, and views the use of assistant supervisors, whom he later refers to as mentors (2006), as a way of providing assistance and feedback regularly. In this study, the researcher served as a mentor where the SI leaders and the researcher met after each SI session to reflect on the session. It was at this forum that the design of the SI pedagogical strategies was redesigned to meet the challenges of the first year engineering students. SI leaders were also involved in designing activities for the SI sessions with the assistance of the researcher. SI leaders were asked to reflect on each of the SI sessions. These journal entries were analysed by the researcher and were also discussed in preparation for the next SI session.

Reflective journals were maintained by the SI leaders throughout the research process. These were used to afford the SI leaders the opportunity to record their thoughts and experiences that related to the research probes in particular. The SI leaders recorded not only what was observed during the SI sessions but also the development of new understanding in terms of student learning, their understanding of the facilitation process as well as how this understanding could have contributed to student learning. Guidelines with respect to structured reflections (see Appendix 2) informed the SI leaders' journal entries. SI leader training also offered training opportunities for SI leaders in making journal entries.

4.3.3. Interviews

Two types of interviews were conducted in this study, viz. two focus group interviews and seven individual interviews.

4.3.3.1. Focus Group Interviews

Focus group interviews and student assessment reports have been used in the reflective phase of the design research process. Patton (1990) suggests that focus group interviews are essential in the evaluation process: as part of a needs assessment, during a program, or months after the completion of a program to gather perceptions on the outcome of that program. Two focus group sessions took place after the 13 week SI programme. Each focus group session was with a different grouping of SI participants. The first session was with the chemical engineering students and the second with all other engineering students.

All focus group interviews were set up in the same way, where students attending the SI sessions were asked to attend the focus group interviews on a voluntary basis. In the other engineering module[19], 8 students attended the session and 12 chemical engineering students attended. Both focus groups were asked the same questions with respect to their engagement in SI sessions in developing an understanding of stoichiometry concepts (see Appendix 3). Each of these focus group interviews were about an hour long and were audio- and video-recorded to ensure that all contributions to the discussions were captured and transcribed. A scribe or research assistant was used to summarise student experiences of engagement, which was noted on a flip chart. This method enhanced the discussion as students' responses served as a trigger that stimulated further responses.

Stewart and Shamdasani (1990) indicate that focus group interviews also assist in interpreting previously obtained qualitative results. In this instance, the focus group interviews assisted in interpreting video recordings of SI sessions.

4.3.3.2. Individual Interviews

Seven participants were interviewed over a period of one month. The planning of the interviews over this short period of time was an important part of the iterative data production process. Participants were chosen for the interviews on the basis of their performance in their class test and examination. SI participants were chosen from each module with a highest, failed and average mark for their examination. The first part of the interview focused on the focus group interviews where the researcher explored in more detail the issues raised by the respondent in the focus group interviews. The second part of the interview focused on participants' test and examination papers with special focus on the stoichiometry section in each assessment. This section attempted to generate a thick description of participants' experiences of the two assessment tasks. Interview questions were semi-structured which allowed for flexibility in establishing students' experiences in the SI sessions (see Appendix 4 for a sample interview transcript).

[19] Refers to all other engineering modules besides chemical engineering such as civil, mechanical, computer, electrical etc.

4.4. Data Analysis

Cohen, Manion & Morrison (2007) state that there is no single or correct way to analyse and present qualitative data; rather, how one does it depends on the issue of *fitness for purpose.* By the principle of *fitness for purpose,* they refer to the researcher being clear about what she wants the data analysis to do, as this determines the kind of analysis that is undertaken. Three data analysis strategies were ultimately utilised to explore engineering students' engagement in chemistry SI. Content analysis was used as the first level of analysis in support of regularities and patterns in the ways that the SI leaders and students acted and interacted as they completed instructional activities and discussed solutions in chemistry SI. This was followed by the use of engagement theory which assisted in the second level of analysis. Having established the categories and completed preliminary data analysis, the second round of data analysis sought to refine and sharpen the categories to answer why the engineering students engaged in the way that they did. The use of engagement theory revealed a new dimension to the evolution of the thesis of this study, which was explained in terms of the phenomenon of space. To move beyond students' engagement and to understand how students get to know stoichiometry concepts I borrowed from Diemers' (2000) model of interpretative space.

4.4.1. Content Analysis

"One of the enduring problems of qualitative data analysis is the reduction of copious amounts of written data to manageable and comprehensible proportions" Cohen, Manion & Morrison (2007: 475). One common procedure for achieving this is through content analysis, a process where 'many words of texts are classified into fewer categories' (Weber 1990:15). Ezzy (2002) suggests that content analysis involves coding, categorising (creating meaningful categories into which the units of analysis can be placed), comparing (categories and making links between them) and concluding or drawing theoretical conclusions from the text. Content analysis also assists with frequency counts (through counting and logging the occurrence of words, codes and categories) developed from the observation schedules in answer the how the environment influenced student engagement during chemistry SI.

The data obtained from the retrospective analysis of the design experiments were analysed through the use of a variant approach of Glaser and Strauss's (1967) constant comparative method. The data was first worked through chronologically, episode by episode, and at each point the current conjectures were tested against the next episode. As a result of this first round of data analysis, a sequence of conjectures and refutations were derived that tied to specific episodes. In the second phase of a retrospective analysis, this sequence of conjectures and refutations of how engineering students engage with stoichiometry concepts in chemistry SI became the data. A hallmark of their method is that, as new data are generated, they are compared with currently conjectured themes or categories. This process of constantly comparing incidents leads to ongoing refinement of the broad theoretical categories developed from the data. As Glaser and Strauss (1967) note, negative cases that appear to contradict a current category are of particular interest and are used to further refine the emerging categories. A deviation from Glaser and Strauss's method used in this study concerns the way in which the results of prior analyses are capitalised upon when a new analysis was being conducted[20]. In Glaser and Strauss's method, theoretical categories or constructs were developed anew from the data in each investigation.

The data was systematically analysed using a bottom-up strategy which aimed to develop conceptual categories from the patterns of description emerging from the data. As soon as the focus group interview data became available, a process of open coding commenced. Open coding, according to Strauss and Corbin (1988), is an analytical task involving three processes:

- Naming concepts
- Defining categories
- Developing categories in terms of their properties and dimensions

Open coding is an attempt by the researcher to open up the text to explore thoughts, ideas and meanings within the text (Strauss and Corbin, 1988). By breaking the data

[20]This method of data analysis was adapted from Cobb et al., 2001.

down into discrete parts, the researcher is able to examine it closely and compare data across sources for similarities and differences. In this study, a first level analysis of the focus group interviews and individual interviews was then circulated to the participants of the focus group interviews and the properties and dimensions of these categories were further developed through clarification. The initial broad categories were refined to two broad categories of description (themes) with respect to how the SI environment influenced learning (pedagogically and socially), and three categories which described how students engaged in chemistry SI (viz. experiential, strategic and social interactions). The data from the retrospective analysis together with the first level analysis of verbatim transcripts of the focus group interviews, observation schedules, individual interviews and video data were triangulated in answering the research questions. The table below denoted codes used in the following chapters to describe each of the instruments used in this study.

Data Source	Code
Observation Schedule	OB
Video Data	VD
Focus Group Interview	FG
SI leader reflective journal	SIRJ
Individual Interview	ID

Table 4.3: Research instrument codes

Design research methodology is used in this study to enable theorisation and understanding of how the SI environment influences student engagement i.e. how, when and why the SI environment influences student engagement. It is the intension of this study to explore and theorise how engineering students engage with stoichiometry concepts in chemistry. Therefore, to explore why these engineering students engage in the way that they do in chemistry SI, a second level of analysis was adopted using engagement theory.

4.4.2. Engagement theory

Kearsley & Shneiderman's (1999) model on engagement theory was used as the second round of data analysis which sought to refine and sharpen the categories to answer why the engineering students engaged in chemistry SI in the way that they do, and to theorise the results of this study. "The fundamental idea underlying engagement theory is that students must be meaningfully engaged in learning activities through interaction with others and worthwhile tasks" (Kearsley & Shneiderman, 1999). Engagement theory has its emphasis on meaningful learning (it is consistent with constructivist approaches), collaboration among peers and a community of students (it can be aligned with situated learning theories), and its focuses on experiential learning. These ideas cohere with the focus of this study. According to Kearsley & Shneiderman (1999), engaged learning can be framed in terms of all student activities involving active cognitive processes such as creating, problem-solving, reasoning, decision-making, and evaluation, which is typical of SI engagement in this study. In addition, it is suggested that students are intrinsically motivated to learn due to the meaningful nature of the learning environment and activities.

The data generated in this study was framed using engagement theory which is well suited to analysing engineering students' engagement in chemistry SI through the notions of *Relate* and *Create* borrowed from Kearsley & Shneiderman (1999), as well as *Reflect,* which was derived from literature and first level analysis in this study.

According to Kearsley & Shneiderman's analysis of student engagement through the first principle, "Relate" refers to studying team efforts that involve looking at how students in chemistry SI communicate, plan, manage and develop social skills during collaborative learning opportunities. They indicate that research on collaborative learning suggests that in the process of collaboration, students are forced to clarify and verbalize their problems, thereby facilitating solutions. The unit of analysis was therefore students' collaborative learning opportunities offered in chemistry SI in determining why they engage in the way that they do. The developed categories from the level one analysis were further refined by systematically working through each of the developed categories as well as its variation in the dimensions of these categories, specifically coding data according to how students communicated, planned, managed, developed social skills and were motivated during collaborative learning activities in chemistry SI.

The second principle "Create", was defined in terms of making learning a creative, purposeful activity. Coding data according to this component complemented the “Relate” component and enabled the researcher to gain insight into how students focus their efforts on application of ideas to a specific context in collaboration, where they were required to work in groups to define the nature of the problem (even if they did not choose the topic), and have a sense of control over their learning which is absent in traditional classroom instruction.

The third principle "Donate" stressed the value of making a useful contribution while learning. Ideally, according to engagement theory, each project has an outside "customer" for whom the project is being conducted. The customer could be a campus group, community organisation, government agency, local business, or needy individual. In this study, however, although problem-based learning principles are used, the aim of the SI sessions was not on project-based learning.

It is argued that students in this study do more reflection in developing an understanding of concepts rather than donate as depicted by Kearsley & Shneiderman. However, there were rare instances of students donating information through engagement to other “needy individuals” (Kearsley & Shneiderman, 1999: 2). Typically, SI sessions observed offered rare instances of voluntary donating of information although there was much discussion, peer collaboration and feedback. The principle *Donate* has more of an assumption that students already know and if they do not know, they cannot donate, which is most often the case. The principle *Reflect* seemed more appropriate because students were found to reflect on their understanding of stoichiometry concepts in developing a better understanding of concepts. Coding data according to the *Reflect* component complemented the *Relate* and C*reate* components in enabling the researcher to gain insight into students' understanding of stoichiometry concepts and allowing for theorisation around why students engaged in particular ways in chemistry SI, which is discussed in Chapter Seven of this study.

This study is therefore analysed according to the terms *Relate* and *Create* were borrowed from Kearsley & Shneiderman (1999) to understand authentic (i.e. meaningful) focus or the orientation which extends the thesis and *Reflect* which was drawn from others such as Leithwood, McAdie, Bascia, & Rodrigue (2006)

4.4.3. Phenomenon of Social Learning Space

The use of engagement theory in the second stage of analysis revealed a new dimension to the evolution of the thesis of this study which was explained in terms of the phenomenon of space. In order to understand how social learning spaces created during SI sessions engage engineering students, the study was analysed using a phenomenological approach to space. Diemers' (2000) model of interpretative space is borrowed, to explain what the phenomenon of space represents in this study

"Phenomenology is a continental European philosophy which is founded on the importance of reflecting on the ways in which the world is made available for intellectual inquiry: this means that it pays particular attention to the active, creative function of language in making the world intelligible" (Johnston, 2000: 579). In an attempt to foreground the voices of the students, the researcher chooses to intersperse analysis on phenomenological space with students' focus group interviews, individual interviews and video data. In this way, an understanding of the role of social learning spaces in chemistry learning is acquired.

The ideas of Diemers (2000), who wrote a paper about interpretative spaces and how these constitute virtual organisations and communities, have been used to extend the data analysis. He makes reference to different spaces present, namely, geographic space, phenomenological space, common interpretative space, cognitive space and the space of social representations. In an attempt to analyse the SI social learning space, the focus of description is on the phenomenological space as described by Diemers and a brief explanation of how the other spatial orientation influences the phenomenological space is given.

Diemers' model is adapted to the chemistry SI social learning space which involves group discussions in analysis of the SI social learning spaces, which is discussed in Chapter Seven of this study. Phenomenological space is, according to Diemers (2000), "the immediate world in sight that arranges itself spatially and temporally around the individual as its centre. External objects in phenomenological space appear to us as phenomena, either through actual perception, attentive advertence or subsidiary awareness, and those perceived phenomena are structured and identified according to our individual set of typifications and meaning-structures, which reside in our cognitive space". He thus argues that we are constantly constructing a meaningful picture of the phenomenological space around us. In this way we are producing the reality of our perceived and unquestioned daily life. In an attempt to theorise students' engagement in the SI social learning space, other spatial orientations such as geographic space, cognitive space and common interpretative space are analysed to determine how they influence the engineering students' phenomenological learning space or the SI learning space.

4.5. Conclusion

This chapter has three main sections: research approach and design, data production plan and data analysis. The research approach and design has revealed that this study is qualitative in nature and is within an interpretative paradigm using a design research methodology. It is iterative in nature and combines research and practice in exploring first year engineering students' engagement in chemistry SI.

The data production plan indicates that this study observed and video recorded 15 SI sessions over a 13 week period, where two focus group interviews were conducted with the engineering students to ascertain their experiences of the chemistry SI the sessions. Seven individual interviews were conducted, where participants were chosen for interviews on the basis of their performance in their class test and examination so as to establish how students from different academic backgrounds engaged in chemistry SI. SI leaders' reflective journal entries also formed part of the production plan. These were used to afford the SI leaders the opportunity to record their thoughts and experiences related to the research probes in particular. The SI leaders recorded not only what was observed during the SI sessions but in addition, they recorded the development of new understanding in terms of student learning, their understanding of the facilitation process as well as how this understanding could have contributed to student learning.

Three data analysis strategies were ultimately utilised to explore engineering students' engagement in chemistry SI. Content analysis was used as the first level of analysis in support of regularities and patterns in the ways that the SI leaders and students acted and interacted as they completed instructional activities and discussed solutions in chemistry SI. This was followed by the use of engagement theory which assisted in the second level of analysis. Having established the categories and completed a preliminary data analysis, the second round of data analysis sought to refine and sharpen the categories to answer why the engineering students engaged in the way that they did. The use of engagement theory revealed a new dimension to the evolution of the thesis of this study, which was explained in terms of the phenomenon of space. To explain what phenomenological space represents in this study, Diemers' (2000) model of interpretative space is outlined. Finally, in coding the data from the focus group interviews, individual interviews and video recordings, the students and the SI leaders have been coded with fictitious names so as to not reveal their identity. This is in the interests of confidentiality and anonymity of the participants.

Having provided the rich detail surrounding the choices made about research methodology and design, the following chapter provides a descriptive analysis in terms of how the chemistry SI environment influences student engagement through content analysis, and attempts to answer the first research question.

CHAPTER FIVE

INFLUENCING STUDENT ENGAGEMENT

5.1. Introduction

The previous chapter focused on how design research methodology was utilised in linking research to practice in chemistry SI sessions within an Interpretative paradigm. This chapter attempts to answer the first research question - How does the chemistry Supplemental Instruction (SI) learning environment influence student engagement? This is achieved through an analysis of the fifteen SI sessions that were observed and video recorded for each of the two first year engineering chemistry modules. It should be emphasised that the gaze in this chapter is on the role of the SI leader in creating social learning spaces in chemistry SI only in attempting to determine how the SI learning spaces influenced students' engagement with stoichiometry concepts. Two focus group interviews were conducted to ascertain students' experiences of the chemistry SI engagement.

Observations of first year engineering students engagement was one of the methods used to generate data during the chemistry SI sessions. Statistical data from the observation schedule and qualitative data from the focus group interviews, video recordings and SI leaders' reflective journal entries have been inserted selectively to estimate the potential measure of the level of student engagement with respect to the influence of the SI learning environment in developing a deep understanding of stoichiometry concepts.

All focus group and interview, observation schedules, video recording and SI leaders' reflective journal entry transcripts were open-coded (see Geisler, 2004; Strauss & Corbin, 1998) according to the categories of description emerging. Focus group interviews and video data revealed various categories of description through content analysis. These were refined to reveal the following themes on how the SI environment influenced student engagement, through spaces for pedagogical learning engagement and social learning engagement. Pedagogical learning engagement refers to ways in which students learn through engagement, whereas social learning engagement refers to the ways in which the students engage with one another.

5.2. Spaces for Pedagogical Learning Engagement

Various categories of description with respect to spaces created for students' pedagogical learning engagement emerged from the data, represented as follows:

- nature of engagement
- development of spaces for higher order thinking and understanding
- variety of learning activities offered
- assessment techniques used

5.2.1. Nature of Engagement

Figure 5.1 shows the different forms of engagement experienced by the students over the fifteen SI sessions observed. Observation schedules revealed students' preferences with respect to the different forms of engagement which are also depicted by the graph below and contribute to the nature of students' engagement in chemistry SI. These values were obtained from a frequency count of the three different forms of engagement per session. An average of all sessions was found.

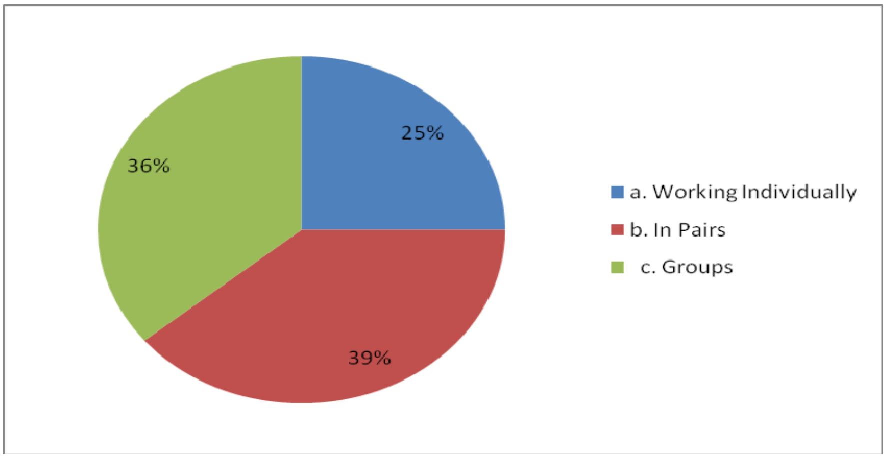

Fig 5.1: Nature of student engagement

From these results it is evident that students were encouraged to work in pairs for 39% of the SI session which indicates a collaborative approach to learning; 36% of the duration of session was spent on group discussion. It is significant to understand the extent to which a learning environment can engage students, according to Trigwell, Prosser, & Waterhouse (1999), as this is often perceived as a strong indicator of the depth and scope of the learning that occurs. Laurillard (2002) and Ramsden (1992), in their seminal texts describing teaching and learning in higher education, often refer to engagement as a critical element underpinning the effectiveness of learning settings.

Collaborative activities can also help to promote deeper levels of knowledge generation (Felder, 2003), and develop initiatives and higher order thinking (McLoughlin, 2000). Another major advantage of active participation as depicted by Gardner, Moll & Pyke (2005), is that participants get the opportunity to develop skills that they need in future collaborative assignments. It has been found that active participation not only helps to increase social interaction and strengthen personal interaction, but also to stimulate activity and motivation among the group members (Soller, 1998).

The focus group interviews (FG) revealed students' experiences of collaborative learning spaces created by the SI leader which described how the SI learning environment contributed to students' engagement during the chemistry SI sessions. Extracts from FG1 with chemical engineering students follows:

> Praveena - *... you get to work in groups and with different people which really clarifies your understanding of chemistry concepts because people might really have different views, methods or ways of working out stuff and...so in that way I think it clarifies chemistry concepts.* [Line 12-14]

> Mbonga – *Working in groups and pairs and having discussions and explanation are also good!* [Line 17-18]

> Nivashan – *I think also that you learn more when you try to teach something to someone - so that helps you learn better.* [Line 23-24]

> Zamo – *We get to work with many people and they have different ideas and so we also get to learn how other people think.* [Line 76-77]

Praveena and Nivashan have similar notions of collaborative learning engagement, where group discussions expose them to a variety of methods of attempting to solve a problem. Since students have different ways of knowing and understanding, these discursive views seem to clarify concepts in stoichiometry for students engaging in discussions. The SI environment also seems to expose students to the different ways of knowing chemistry concepts.

Mbonga expressed the view that he values the group and paired discussions but does not elaborate on why he does so. It can be speculated that perhaps that this was due to the interactive nature of learning which these pedagogical methods exemplified. This was the students' first instinctive response to the question 'What are your experiences of the chemistry SI sessions?' Nivashan, in contrast, recognised that his understanding improves by trying to teach other students stoichiometry concepts. These responses perhaps indicate that students value the social learning spaces created through collaboration in an SI learning environment, which offers different dimensions to teaching and learning from their chemistry lectures.

SI leaders' reflective journal (SIL) indicate that SI leaders encouraged engagement with stoichiometry concepts through paired problem solving and student explanation, as expressed in the following excerpt:

> ...I *encouraged students to work together and discuss the solution and one of them was asked to come to the board to explain their understanding of the concept of product formation.* [SIL1][24/09/09]

The nature of engagement in the chemistry SI sessions seems to be dominated by a collaborative learning space. However, individual learning also features strongly as a means of engaging with chemistry concepts. There could be several reasons for individual engagement, such as students' lack of confidence in participation and their being accustomed to the lecture structure of passive learning.

5.2.2. Development of spaces for higher order thinking skills

Spaces for Higher Order Thinking Skills (HOTS) as defined by Blooms taxonomy see footnote 8 were developed by SI leaders through the use of SI pedagogical methods. Figure 5.2 represents the observations of how SI leaders developed these spaces for higher order thinking and a deeper understanding of stoichiometry concepts. The results were derived from observation of fifteen SI sessions. The different pedagogical techniques used by the SI leader were noted in creating spaces for deeper understanding and higher order thinking skills (HOTS) around stoichiometry concepts, to gain some sense of the way in which the SI leaders influenced the depth and breadth of student learning during SI sessions.

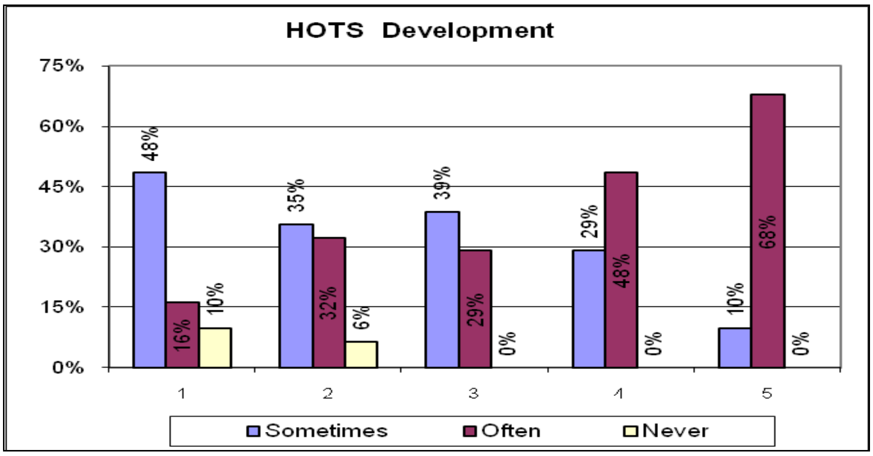

Figure 5.2: Development of HOTS and understanding

Key to figure 5.2 on HOTS Development

1. asking higher-order questions
2. engaging in activities that require higher order thinking
3. asking open-ended questions
4. instigating students to reflect on their own thinking
5. providing examples of application of stoichiometry concepts

It is evident that providing students with good examples and formulating links with different situations dominated the SI sessions in developing spaces for HOTS and a deep understanding of stoichiometry. For the purposes of this study, deep understanding refers to understanding not only about specific areas of knowledge but also about problem solving processes, including what is sometimes referred to as meta-cognition, an understanding of one's own thought processes (Liethwood, McAdie, Bascia, & Rodrigue, 2006).

Engaging in reflective practices and activities that required higher-order thinking were encouraged as the next commonly used practices during SI sessions, which is evident in Fig. 5.2. These practices were also observed when students were asked by the SI leader to criticise statements with respect to stoichiometry or evaluate answers put on the chalkboard. Biggs (1999) claims that an important aim in promoting engagement and interest in a learning environment is to encourage the acquisition of deep rather than shallow knowledge and higher-order thinking skills.

Students' pedagogical engagement in chemistry SI seemed to be dominated by the formation of collaborative group discussions or paired problem solving. However, individual learning moments also played a significant part in the session.

The SI environment can also be regarded as structurally influencing students' engagement by creating spaces for higher order thinking and deep understanding of chemistry concepts. This was achieved through an environment which made use of different pedagogical techniques such as reflective practice, encouraging students to substantiate their claims and evaluative practices, which played a major role in developing a culture of critical reflection.

Table 5.1: Methods of high level skills development

SI leaders developed high level skills through:	% per session
a. modelling	23
b. practice	42
c. feedback of content knowledge	55

SI leaders attempted to develop higher-order thinking and deep understanding through modelling higher-order questions, practice in answering higher order type questions and feedback that involved justification of stoichiometry concepts during discussions. Students were also asked to attempt tasks that involved critical evaluation, which is reflected by the following statement from the SI leaders' reflections on [05/10/09]:

> *To develop students' understanding and critical thinking I used a worksheet that showed two solutions of stoichiometric problems involving calculation of mass and mass %. It was interesting to note that students were engaged in questioning each step of the solution in trying to develop an understanding of the problem solution.* [SIL 2]

Practice and feedback also supported students in developing deep understanding and higher order thinking which is evident by one SI Leader's comment:

I found that students were not just accepting answers but rather questioning why certain values were used as opposed to others. [SIL 2][19/10/09]

The following excerpt from the video data (VD8) indicates the effect of SI leader feedback on student engagement:

SIL2: *Someone wants to know "what about the oxygen?" What about the oxygen? What is a hydrocarbon made up of?*

Joe: *It's only well – it's not part of the original mass – it is only made up of hydrogen and carbon.*

SIL2: *Hydrogen and carbon. It's a hydrocarbon – what does that tell you?*

Joe: *No oxygen.*

SIL2: *There's no oxygen. Do you all agree – no oxygen – if it's a hydrocarbon then it contains no oxygen. Is carbon dioxide a hydrocarbon?*

Zama: *Hydrocarbon has carbon and hydrogen whereas carbon dioxide has carbon and oxygen.*

SIL2: *Yes. So there you have your answer.* [Lines 71 – 84]

In the above excerpt, the SI leader (SIL) redirects a question from one of the students to the class with respect to the query "*what about the oxygen*". Given that she does not get a response, she continues to probe, asking what is it made of and through constant prompting and rephrasing of the question; John then responds. The SIL2 then re-enforces the response from Joe by saying "hydrogen and carbon". She gives them a collective name and pushes them beyond just knowing to understanding about hydrocarbon. This is done when she has them understand that there is no oxygen. The SIL then goes from the particular to general and feeds back to everyone by asking the rest of the students, "*Do you all agree*". She then tries to verify that they know that there is no oxygen by asking them whether carbon dioxide is a hydrocarbon. In effect she is asking the students to reflect on their understanding

It is evident that higher order thinking skills are developed through modelling of higher questions, practise of higher order reasoning and evaluation, and feedback that supports and constructs students' understanding through engagement. Different types of assessment techniques were used by the SI leader to assess the development of these higher order thinking skills and the understanding of stoichiometry concepts.

5.2.3. Types of Learning Activities

As an exploration of the capacity of such an environment to motivate and encourage student participation, the different types of learning activities offered in a SI session were compared over all 15 sessions that were observed. Table 5.2 shows the different types of learning activities students engaged in during an SI session and the frequency of these activities observed over the fifteen sessions.

Table 5.2: Learning Activities

Types of learning activities offered to encourage participation	Number of Sessions	Percentage
a. Group discussion	11	74
b. Individual presentations	15	100
c. Visual techniques	15	100
d. Paired problem solving	15	100

It can be seen from table 5.2 that individual presentations, visual techniques and paired problem solving were techniques used in all SI sessions. However, group discussions featured only 74% of the time, which was sometimes due to small numbers of students attending. SI leaders' reflective journal entry (Appendix 2) revealed the following with respect to the use of visual techniques:

> *…students' were unable to understand certain questions/concepts until something was written/drawn on the board. Seeing a relevant diagram or equation, appeared to trigger their memory and encourage better understanding*. [SIL 2][29/08/09]

The reflection above by the SI leader indicated that the use of visuals e.g. diagrams, models, and pictures contributed to developing better understanding of stoichiometry concepts. This is most likely due to a preference for a visual style of learning.

Paired problem solving and working individually seemed to be the preferred means of interaction. In some instances, students found it more secure to talk to the person next to them than contributing to a group discussion, probably because of being insecure about their answers. Individual presentations occurred regularly in all SI sessions as SI leaders developed social norms where students were required to explain concepts in their own words and justify their reasoning, contribute to whole class discussions and clarify their understanding of concepts by questioning feedback received from the SI leader or other students in the SI session.

To assess the development of deeper understanding and higher-order thinking skills of stoichiometry concepts, the different types of questions students were asking with respect to their problem solving activity, were analysed over the 15 week period.

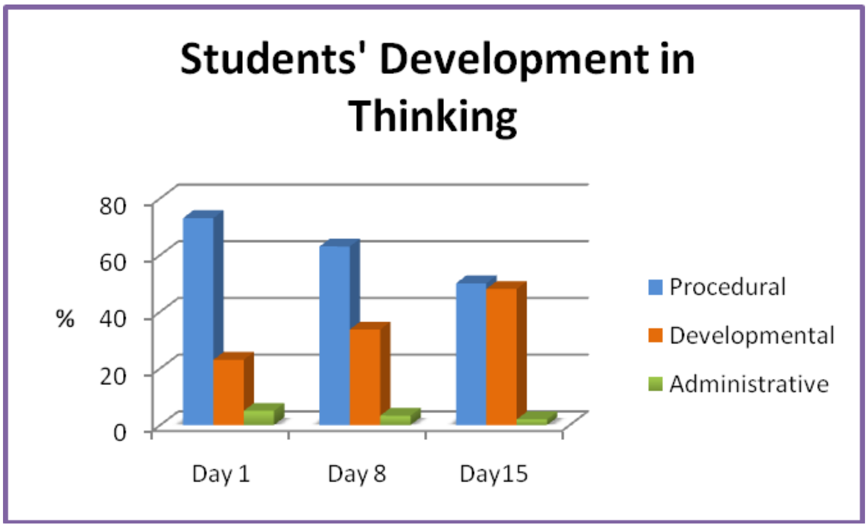

Figure 5.3: Students' Development in thinking

A comparison of the different types of questions students asked during each session was analysed. Fig. 5.3 represents changes in students learning locus with respect to their development in thinking skills and reasoning with stoichiometry concepts. The observation schedule data revealed that during the initial SI sessions on stoichiometry, 72% of the questions were based on **procedural** type questions, such as:

How do you determine the products of a reaction?

How do we know what products form?

How do we calculate the limiting reagent?

A few **developmental** questions were asked, which constituted 23% of the questions:

Why do we calculate the number of moles of $CaCO_3$ *twice?*

How would we recognize a combustion analysis reaction?

Why is SO_2 *a neutral compound with no charge?*

The remaining (5%) of the questions were **administrative** type questions, such as the following:

How long do we get to work on this problem?

Towards the later part of the fifteen observations conducted, it was found that 50% of the questions asked were procedural, 48% were developmental and a mere 2% were administrative type questions. These results support the finding in Table 5.1 above (developed through frequency counts of the fifteen SI sessions observed with respect to methods used by the SI leader in developing HOTS). This indicates that practice and constant feedback played a major role in developing higher-order thinking skills. SI leaders' reflective journals also revealed that:

> *…students' were asking procedural and administrative type questions. They basically wanted to know how to get to an answer, but were not really trying to understand the bigger picture or see how things are actually connected to each other.* [SIL2][24/07/09]

This reflection by SIL 2 was captured during the very first SI session observed and revealed her perceptions of students attending SI. SIL2 felt that students regarded SI initially as being a space for retrieving answers rather than developing an understanding of chemistry concepts, which was probably due to the students' assumptions that SI was going to offer a similar experience to their tutorial sessions.

The results derived from the questions above also concur with Jos'e, Teixeira-Dias, Jesus, Francisi & Watts (2005), who noted that the number of 'transformative' questions increase across a semester, pointing to an improvement in the quality of the students' questions. In this instance, 'transformative' and 'developmental' questions are synonymous with respect to being associated with reorganisation and restructuring of knowledge, so that students are able to hypothesize, deduce, look for inferences and make improvements in their knowledge.

5.2.4. Types of Assessment techniques used

Table 5.3 below represents frequency scores of the informal assessment techniques used by the SI leaders to assess students' understanding of stoichiometry concepts which were derived from the fifteen SI sessions observed.

Table 5.3: Assessment Techniques

Assessment techniques used by SI leaders	% frequency
a. Drawing concept maps	4
b. Informal Quiz	6
c. Asking Probing questions	58
d. Problem solving	40
Total	100

In order to assess the frequency of assessment techniques represented by Table 5.3 above, an average representation of these techniques used in all fifteen SI sessions observed was taken. It was found that *asking probing questions* (58%) was the most frequently used assessment tool in all fifteen sessions observed. This was followed by *problem solving activities* (40%), which involved students explaining their answers on the board, followed by *informal quiz* (6%) and *drawing concept maps* (4%).

Open-ended questions and probing questions were used to assist the SI leader to understand more clearly how students think, what prior knowledge existed, and what understandings students gained during group discussion and oral presentation, as reflected below:

> *I asked probing questions during the session to encourage students to think about the solutions…* [SIL 2][16/08/09]
> *I had to use redirecting and probing questions because only a select few students were responding or answering the questions posed…*[SIL 1][17/08/09]

As indicated by the excerpt, probing and redirecting questions were also used to engage students in the discussions and encourage deeper thinking. The SI leaders' reflections also revealed that:

> *…probing questions did not always achieve the desired results of engaging students or getting them to reflect on their understanding…*[SIL 2][21/09/09]

Probing questions in some instances resulted in no response from students which is probably because probing is dependent on students' prior knowledge of concepts.

The SI leader also posed open-ended questions as well as probing questions to the students as a means of modelling and developing critical thinking skills with the students. This is revealed by the SI leaders' reflections [SIL2] on [19/10/09]:

> *I asked many higher order questions in this session and I found that students were also not just accepting answers but rather questioning why certain values were used as opposed to others. They were questioning as to why specific units were being used in calculations. They asked questions such as:*
> *Why would do you use dm^3 (unit for volume) instead of cm^3 in that calculation*?

The excerpt above confirms that modeling higher order questions stimulates students to ask higher order type questions according to Blooms taxonomy as discussed in Section 4.2.4 of Chapter Four.

There are various ways to assess higher-order thinking in the literature; one of them is open-ended assessment (Zohar, 2004). Concept maps were used most often at the end of a section as a means of developing a summary of concepts learnt. Concept maps also provide a portrayal of an individual's mental representation of a concept (Edmondson, 2000). SI leaders' reflective journal entries revealed that:

> *…students showed an understanding of concepts discussed as they were able to draw concept maps…*[SIL1][16/08/09]

This implies that concept maps were used as a form of assessment of students' understanding of stoichiometry concepts.

Different assessment techniques were utilised by the SI leaders in the SI social learning spaces to assess students' understanding of stoichiometry concepts, which also served as a means of feedback and reflection for students. Kearsley & Shneiderman (1998) argue that engaged learning occurs in settings which involve active cognitive processes such as creating, problem solving, reasoning, decision making and evaluation.

5.3. Spaces for social learning engagement

Observation schedules and video data also served to demonstrate how SI leaders created spaces for social learning engagement in chemistry SI sessions. The following themes were developed from the video data, viz. invitations for social space and development of socio-scientific norms.

5.3.1. Invitations for Social learning Spaces

The excerpt below from (VD10) demonstrates the SI leaders' attempts to invite students to engage in the social learning spaces created in the chemistry SI session. One of the ways the SI leader created these spaces was by selecting a volunteer from the class to write and explain his/her solution to a problem. This is depicted in the following excerpt which uses stoichiometric relationships to calculate concentration of sodium carbonate:

SIL1*: Ursula is going to come up to the board and explain to us how she answered question 2(a). If you have any questions for her feel free to ask.*

Ursula: *The first thing to do is find the number of moles of* Na_2CO_3 *using the formula, 'n' is equal to 'm' over molar mass. Then substitute the molar mass which is 106 grams per mol. The answer is 0.0635 mol.*

SIL1*: See, that is step one - finding the number of moles. Well done! What is the next step?*

Ursula: *The next step is to calculate the concentration; 'm' is equal to 'n' over 'v'. We have the number of moles, 0.0635 mol, and the 'v' we convert to litres by dividing by a thousand and the answer is 0.254 mol per litre.*

SIL1*: Thank you. Give her a clap. That was well done! Did everyone get this answer?*

Chorus response*: Yes.*

SIL1: *There is a question here. Is there a difference in the units, if you write 'M' or 'mol/L' or 'mol/dm^3'? Is there a difference?*

Chorus response: *No.*

SIL1: *Are they all the same?*

Chorus response: *Yes, they are the same.* [Lines 8 – 22]

From the excerpt above it is evident that the SI leader creates invitations for engagement by selecting a volunteer from the class to write and explain her answer to a problem using stoichiometric relationships. In this problem, the student is required to calculate the concentration of sodium carbonate (Na_2CO_3). She reminds students of the social norms of engaging at chemistry SI sessions, that they are most welcome to ask the student who is explaining the problem anything they are uncertain about with respect to her explanation. The SI leader summarises after each step to ensure that students follow the reasoning and are given opportunities to reflect on their understanding of concepts. She also motivates the student to answer through words of encouragement ("*Well done*") and prompts the student to continue by asking,"What is the next step?" The student is further motivated for her contribution by being thanked, which in a sense encourages the students to contribute and shows that their contribution is valued.

Further invitations to gain clarity with respect to answers presented by the students are invited by the SI leader, who asks: "Did everyone get that answer?" This question initiates a chorus response which does not give the SI leader a clear indication whether all students understood the solution to the problem. The SI leader falls short of establishing whether students understand the difference ways the units for concentration can be written by not asking a higher order question with respect to Bloom's Taxonomy. The SI leaders' level of questioning with reference to Blooms Taxonomy does not, however, elicit a response that depicts understanding but rather a chorus response that repeats the SI leaders' actual words, for example, "Yes, they are all the same".

The focus group interviews also revealed that invitations to engage in group or paired discussions encouraged students to develop self-confidence as well as motivation to learn in this environment, which is depicted by the following excerpt from FG2:

Thuli - *Group work boosts your confidence.*
Rishan - *If you discuss the answer in a pair you feel more sure of your answer.*
Bonga - *Discussing in pairs first helps in answering in front of the class.*
Makousa – *In the beginning of the year I wasn't so confident about putting my answers on the board but then as I kept coming to SI, I realised that we are all here with our questions and problems and so if my answer is wrong it is fine because someone is going to correct me and then at least I learn from that and I don't make that mistake again. So, it's has been quite helpful.*

Although many different invitations are created for the students to engage in the social learning spaces, all of the instances do not necessarily persuade all students to engage in developing a deeper understanding of stoichiometry concepts. This is evident from the chorus answers which did not demonstrate a deep understanding of concepts. The following excerpt from the focus group interview [FG1] indicates that yes/no type responses do not get students to reflect on what they understand by certain concepts:

Noma - *You need to put answers into your own words when she asks us what we know about that question and she asks us to explain in our own words and usually uses the feedback thing, where she asks what do you understand by that question? Sometimes someone will say "Yes, yes I understand" but when you ask them to explain or say it back they cannot because they don't understand.* [FGI1, Line 69-74]

In this instance, the student suggests that the SI leader creates invitations to engage in the social learning spaces by asking students to reflect on their understanding, by asking higher order questions according to Bloom's Taxonomy, and further indicates that asking questions such as "*Do you understand*?" does not necessarily reflect a true perception of students' understanding of concepts.

The conversation above indicates that the SI leader created invitations for the students to participate in the chemistry SI social learning environment through motivation, support, encouragement and the use of different pedagogical strategies such as group/peer discussions and students' explanations, as well as the use of redirecting and probing questions. All invitations did not effectively assess students' engagement with stoichiometry concepts, which suggests that creating invitations for engagement through questioning should focus on asking higher order questions rather than lower order ones, to effectively assess students' understanding of concepts.

5.4. Development of Socio-scientific norms

Socio- scientific norms seem to influence the SI environment in developing student engagement in chemistry SI through the discursive establishment of consensus on the multiple constructions of responses received for a particular problem.

The following excerpt represents discussions from video data [VD3], where students were working on a problem that first required them to determine the limiting reagent in the reaction and then calculate the theoretical yield of Vanadium. One of the students had explained how to determine the limiting reagent but there seemed to be some confusion with respect to determining the theoretical yield of Vanadium. This is depicted by the conversation below:

SIL2: *Who can tell us what yield means? (Pause) What does it mean when you say theoretical yield?*

Rosanne**:** *How much of V is actually produced?*

SIL2*:* *How much of vanadium is actually produced. So if theoretical yield means how much of vanadium is actually produced then what is the actual yield? (Pause) What would you associate the word yield with?*

Rosanne**:** *Percentage.*

SIL2*:* *Percentage, anyone else? (Pause) What does the word yield mean to you?*

Stembile: *What you discover.*

SIL2**:** *Anyone wants to help her?*

Nick**:** *Quantity produced.*

Researcher***:*** *What is the quantity in this question that we need to find?*

Yatish**:** *Mass.*

SIL2**:** *It's the mass, yes. So whenever you see the word yield, you will associate it with mass. Do you all agree? (Pause) So what is the difference between actual and theoretical yield?* [Line 29-48]

The SI leader begins the discussion by trying to establish if students understand the concepts of *yield* and *theoretical yield*. Rosanne has an idea that yield is associated with the amount of product formed but is confused with the concepts *actual* and *theoretical yield*. The SI leader picks up on this confusion and asks her to explain the difference between the two concepts. There is a pause in the discussion but the student fails to answer the question so the SI leader tries to clarify or make explicit the meaning of the word *yield* rather than the difference in meaning between actual and theoretical. The SI leader's question "*What would you associate the word yield with?"* seems to confuse students as Rosanne responds *"Percentage"* and Stembile responds *"What you discover"*. Rosanne seems confused by the question since she previously displayed an understanding of the word yield. Stembile, in contrast, shows a lack of understanding of the word and therefore probably has difficulty solving the problem. The SI leader fails to probe the students' understanding of the concept at this point but simply asks another student to assist her with the answer. Nick then suggests that *yield* refers to quantity produced and Yatish finally concludes that it actually means mass-produced. After establishing the discursive views of students on the meaning of *yield,* the SI leader then inquires if all students are in agreement with the answer. It should be noted how the SI leader institutionalises a community of agreement and understanding when no one responds or contests her consensus-making. This is another way social norms are created in the SI learning environment.

The dialogue above indicates that the SI leader attempts to achieve consensus in understanding amongst the students in the social learning space through unpacking terminology, rephrasing questions, redirecting questions and summarising concepts.

The individual interviews [ID5] further suggest that consensus is also reached by the SI leaders' attempts to ensure that all students have arrived at the same answer through facilitation techniques, by walking around the classroom and questioning individuals and groups with respect to how they came up with their answers. This is illustrated by the following comment:

> *…she checks if everyone has the same answer and if somebody doesn't have the answer she will ask that person to explain how they arrived at their answer on the board or ask someone else to explain why it is that way.* [Line 90-92]

These comments suggest that the SI leader also establishes consensus with respect to understanding concepts through allowing students the opportunity to reflect on their understanding.

Students are aware of the different views that are generated in class discussions and value these discursive views in developing a better understanding of chemistry concepts, which is depicted in the following excerpt from FG1:

Zamo – *You get to work with many people and they have different ideas and so we also get to learn how other people think. Sometimes you can't do your things on your own - you know something about the question and someone else knows how to start then someone in the group assists you because they know something and we carry on from there. We assist each other actually.* [Line 76-81]

Zamo explains that discussions at SI session enabled her to experience a variety of different ideas on how to attempt different stoichiometry problems. She realises that learning is a social endeavour rather than an individual task to achieve conceptual understanding.

At present the first year chemistry curriculum limits the possibility for information processing and knowledge construction in a collaborative, constructivist manner considering the didactic form of lectures. The vast array of concepts and content to be studied is also too extensive in relation to the time and the number of students per module. Students adapt their study strategies to the requirements of the examinations rather than become interested in acquisition of deeper understanding of knowledge. In light of this situation, Supplemental Instruction has been introduced to provide the support that is needed in order to assist the first year students in the processing of information within a peer collaboration environment.

The data sets generated revealed that student engagement in the SI sessions is driven by the SI leader's feedback, the invitation to engage in explorations and negotiations, as well as discursive establishment of consensus. The social learning space created encouraged explanations, conceptual understanding, and the promotion of social engagement through discursive activity (questioning, small group discussion, debate and reflection).

Creating spaces for students to take control of and responsibility for their learning can greatly enhance their ability to learn from experience. Bransford, Brown and Cocking (2002) argue for the development of meta-cognitive skills to promote active learning. By developing their effectiveness as learners (Keeton, Sheckley & Griggs, 2002), students can be empowered to take responsibility for their own learning by understanding how they learn best and the skills necessary to learn in regions that are uncomfortable for them.

First year students are usually not in the habit of taking responsibility for their studies but prefer to do what is obligatory, i.e. that which has been decided and planned by someone else which comes to a large extent from their secondary school experience (Mannikko-Barbutiu & Sjogrund, 2004). Since SI is based on voluntarism it can become a difficult task to motivate students to participate. The SI leaders' role in creating interactive learning spaces in these instances becomes vital in giving students opportunities to take responsibility for their learning.

Data reveal that the relationship between the SI leader and the participating students was assessment-free. The students did not have to try and hide their ignorance or weakness in a SI session situation as they might have done in a lecture for fear of receiving a poor grade or judgment against them. Damasio (1994, 2003), LeDoux (1997) and Zull (2002) offer convincing research evidence that reason and emotion are inextricably related in their influence on learning and memory. According to Kolb & Kolb (2005), it appears that feelings and emotions have primacy in determining whether and what we learn. Negative emotions such as fear and anxiety can block learning, while positive feelings of attraction and interest may be essential for learning. To learn something that one is not interested in is extremely difficult. It is here that the SI leaders' role becomes extremely important in creating innovative social learning spaces that encourage and motivate students to learn, as suggested by the results of this study.

In the constructivist point of view, the role of the SI leader is to facilitate learning through guiding the students in their thinking and instead of directly providing the right answer, making them seek for the right answer themselves. It was evident that the expectations of the students towards the SI leader, especially in the beginning, were the same as they had towards a tutor or lecturer. They saw the SI leader as a person with the knowledge and the willingness to tell what was right and what was wrong. Only later did the students realise that there might be benefits in not receiving the right answer but actually struggling through common efforts toward a solution. The 'common struggle' or profound discussion of the problem was seen to lead to a deeper understanding of the phenomenon and its function, and its relation to other phenomena.

5.5 Conclusion

This chapter has revealed that the SI learning environment influences engagement through the ways students learn either collaboratively or through individual learning activities, making use of different pedagogical methods such as the different types of questions asked by SI leaders and students, learning activities offered and assessment tasks intended to engage students. Socially, the environment influences engagement through the creation of social learning spaces. Lastly, the development of socio-scientific norms plays a role in establishing consensus with respect to group discussions. Boud & Prosser (2002) describe four principles that they argue are necessary for an effective learning environment: a context for learning that acknowledges the student's contexts and needs; challenge for the student; cognitively engaging contexts, and opportunities to practise and use the application of the knowledge, skills and understandings being developed. This chapter reveals that the SI learning environment coheres with Boud & Prosser's principles of what constitutes an effective learning environment in most instances.

The next chapter will discuss the second research question, which is how the engineering students engage in chemistry SI.

CHAPTER SIX

INSIGHTS INTO LEARNING THROUGH ENGAGEMENT

6.1 Introduction

This chapter attempts to answer the second research question: How do the first year engineering students engage in the chemistry SI environment? It follows from the discussion in the previous chapter, which addressed the first research question: How does the chemistry Supplemental Instruction (SI) learning environment influence student engagement? Statistical data from the observation schedule and qualitative data from the focus group interviews and SI leaders' reflective journal entries were selectively inserted to estimate the potential measure of the level of student engagement in developing an understanding of stoichiometry concepts. This chapter makes use of qualitative data from two focus group interviews. Video data of SI sessions has been inserted selectively to determine how students engage in the chemistry SI sessions. The theoretical intent of a design experiment was to identify and account for successive patterns in students' thinking with respect to the relationship between SI classroom norms and standards and students' learning of stoichiometry concepts. Data which reflects patterns in students' thinking with respect to developing an understanding of stoichiometry concepts are dispersed throughout this chapter in an attempt to answer the research question.

Three broad themes were derived from the data with respect to the conjectured local theories developed from the design research methodology that described students' engagement in chemistry SI viz. experientially, social learning engagement and strategically, all of which will be elaborated on in this chapter. Students' engagement is framed as experiential because of the ways in which they experience the chemistry SI sessions; social because of collaborative ways in which they engage, and strategic in terms of the ways they develop strategies for engaging in chemistry SI. It should be noted that there is some degree of overlap in the way the environment influences chemistry learning and the way in which the engineering students engage with chemistry. This is because the focus of analysis is on both the SI leader and the engineering students in determining how the students engage with stoichiometry concepts in chemistry SI. This chapter foregrounds engineering students' engagement in chemistry SI in developing an understanding of stoichiometry concepts.

6.2. Experiential learning

The first year engineering students from each of the two chemistry modules, viz. chemical engineers and all other engineers observed and interviewed demonstrated similar understandings of how they experience chemistry SI sessions in getting to know chemistry concepts depicted through the following categories of description: feedback and support, developing an understanding through reflection, collaboration, motivation to learn and practice.

6.2.1 Feedback and Support

SI leader feedback seems to be a vital component to students' understanding of chemistry concepts and, according to the responses below, happens in several ways viz. through SI leader attentiveness, summarisation and explanation of concepts and confirmation of answers. The following excerpts compare and contrast students' responses from focus group discussions with SI leaders' attempts at providing feedback from the transcripts of video recording of the SI sessions as well as individual interviews with students:

> Noma - *I'd say I like the fact that they pay special attention to every person's needs and you are given a chance to explain something in your own words, therefore you know whether you've finally got something or the rhythm of something or not.* [FG1; Lines 5-8]

The student initially mentions that she enjoys the individual attention that students receive at SI, which probably translates into the fact that feedback happens in several ways, in this case through SI leader attentiveness. The student thereafter goes on to say that being given a chance to explain something in your own words gives you an indication as to whether you understand the concept. This shows that the student is aware of how she learns. Other students describe different forms of feedback received from the SI leader:

> Praveena - S*he is always there to explain the concept or say whether your answer is correct or your understanding is correct. She confirms your answers which is encouraging.* [FG1; Lines 185-187]

This regular feedback is evident from the video transcripts (VD2, in Appendix 5), where the SI leader explains the use of significant figures in empirical formula calculations which involve developing ratios of elements with respect to each other in a compound.

> SIL 2: *They have given you masses in your question - which is a good guide as to how many significant figures to use. Each one you can see has four significant figures. So, I suggest when you working out mass, molar mass or moles, stick to four significant figures so your ratios don't go too far off. Instead of using all the numbers on your calculator because you would get different ratios like you did.* [VD12; Lines 240-244]

The above excerpt describes the SI leader's explanation of the use of significant figures in stoichiometry calculations which are vital in obtaining the correct answer because of the use of ratios. For example, in the calculation of empirical formulae, the initial ratio calculated is the number of moles of each of the elements. This is followed by the calculation of the empirical formulae which involves taking the smallest mole ratio determined from the elements in the compound and dividing it by the number of moles of each of the elements, thus obtaining the empirical formula C_2H_4. Further, the SI leader also confirms answers which seem to be an important aspect in the learning and understanding, as noted by the student. SI leaders confirm students' answers with remarks such as "*Well done! You guys can carry on with the next section*". These comments are deemed essential in motivating students and provide feedback for students to proceed in answering other questions.

Data from transcripts of video recordings (VD2) of chemistry SI sessions further reveal that students also received feedback through the summarisation of concepts and procedures learnt, depicted as follows:

SIL: *Step 1 of combustion analysis. What would you do?*

John**:** *Find the number of moles.*

SIL**:** *So, first step for combustion analysis problems is - find the number of moles of each element. Based on what you have, you can find the number of moles of carbon and hydrogen. Then if there's oxygen present then what do we have to do to find the mass of oxygen?*

John**:** *Minus the carbon.*

SIL**:** *Once you've got the mass of C and H, we can find the mass of – an oxygen containing compound – next we can find the mass of O. What is the next step?*

Adam**:** *After we have found this mass, we can find the number of moles.*

Researcher**:** *So how do we actually find the mass of oxygen from carbon and hydrogen? Anyone?*

Sam**:** *You subtract the sum of the mass of the carbon and hydrogen from the mass of the sample.*

SIL **:** *You all now know the number of moles of each one of the elements. I'll just call it "x", "y" and "z", and then you'll just have to find the simplest – the empirical formula, the ratio based on the numbers.* [VD2; Lines 208-238]

In the above dialogue, the SI leader provides feedback with respect to concepts learnt in the calculation of empirical formula (simplest ratio of elements in a compound) for combustion analysis which refers to compounds that burn in an excess of oxygen. This reaction is explained in the form of a summary of steps to follow which is evident in the students' response below where she claims to value the skills she learns in SI with respect to answering stoichiometry problems. It is clear that students' understanding is being probed in developing these generic steps to follow in calculations of empirical formula. The researcher in the above instance serves as a mentor to the SI leader modelling facilitation skills which allowed students to reflect a clear understanding of concepts learnt.

Students identify that they learn best through the development of certain skills which aid in the learning process. This is depicted as follows:

> *I think that when it comes to stoichiometry there is a set method in which you can apply stuff or there is an order actually and at these SI sessions we have been able to identify that order and carry that through which is something that we are unable to do , or find difficult during lectures*. [FG1; Lines 45-48]

In this excerpt the student ascertains that there are certain skills (see Table 5.1, chapter five) that need to be developed in order to answer stoichiometry problems which she refers to as "*an order*". This order is demonstrated in the previous excerpt from the video data (VD2) which demonstrates the SI leader's summation of concepts learnt thought the development of generic steps to follow in problem solving of different concepts in stoichiometry. Besides developing skills in answering questions, students recognise that they also develop their own understanding of concepts through discussion and engagement with concepts.

> *…we developed our own way of understanding it because it is not easy to understand the thing from the textbook and lectures because those words are so much and I don't know*. [FG1; Lines 51-53]

This student is aware of how he learns: he needs to develop/construct his own understanding of concepts. This idea is further elaborated by Nivashan, who states: *…but if you understand a concept, there will be no need to' by heart' the question and because you have gone through and understood the question you are able to answer the question*. [FG1; Lines 125-127] This student displays awareness that learning involves understanding and not memorisation. Amanda refers to the organisational and interpretation skills she developed in SI when she remarks, "*I learnt how to lay out my work properly and write all my information from the question so then it is easier, you see everything*". [FG2; Lines 37-40] This student claims that these organisational skills assist her in determining what information is given and what needs to be calculated which she describes as improving her understanding of the question at hand.

Developing reflective summaries of concepts learnt seemed to be a regular activity in the chemistry SI sessions in order to engage students to reflect on stoichiometry concepts learnt. This is also evident in another SI session observed on determining the percentage yield of a product in [VD3]:

SIL 1**:** *Now just to complete, let's just recap the steps that you would take to answer a question like this (refers to Percentage Yield questions). If you get a question that gives you 2 things reacting to form a product and you have to find out how much is formed, what are the steps you gonna take? Think back to the beginning. What steps did we take?*

Nithu**:** *Find the number of moles*

SIL 1: *Calculate the number of moles of the reactants. Once we've calculated the number of moles of reactants, what would be our next step?*

Stacy**:** *[Student speaks inaudibly]*

SIL 1*: Mole ratios and… you gonna look at the molar relationships* (SI leader repeats students response)

Stacy*: [Student speaks inaudibly]*

SIL 1*: Look at the stoichiometric relationship between each reactant and the product formed.* (SI leader repeats student's response) *Next step?*

Quniton**:** *Limiting reagent.*

SIL 1*: Identify the limiting reagent. Next step?*

Stacy*: Calculate the mass of the required product. [Continues inaudibly]*

SIL 1*: That would give you your yield, right. And thereafter you're required to calculate the percentage yield.* [Lines 148-160]

This form of feedback serves to summarise concepts learnt and demonstrates how the SI leaders provide feedback through repetition of students' responses and in some instances, refines students' responses. One of the participants in the focus group interview [FG2] reveals that he views the lecturer merely as a source of information who does not allow for a deeper understanding of concepts and acknowledges that the pace of the lecture is different to SI sessions. This is represented by the following remark: "*the lecturer just thinks about the materials he wants to gives us but if you try to just to ask something to the lecturer he goes so fast and he does not think to explain* *to everybody… in SI you can ask anything there they are going to explain you ... they can get time to just make you understand what you need to know".* [Lines 22-26]

The student further believes that there are opportunities during the SI sessions to get an explanation or the SI leaders make the time to make you understand. Here again, this students' understanding of learning involves the "didactic model" which is in conflict with the constructivist theory of learning. The latter argues that no one can make you understand but that learning as an active process with students taking responsibility for knowledge construction.

Other students view their peers as a resource in their learning which is reflected by Amanda's comment in [FG2; Lines 96-97]: "*If you talk about it you realise your mistakes and there is an opportunity for other people to correct you",* as she receives feedback with respect to her understanding of concepts.

The following excerpts from the video data [VD5] indicate the effect of SI leader feedback on student engagement:

SIL1:	*I would like Purushen to explain how his group found the limiting reagent when 1.5g of NaOH reacted with 0.70g of HCl.*
Purushen:	*We first balanced the equation.*
SIL2:	*Well done. What is the next step?*
Purushen:	*We found the number of moles of NaOH and HCl?*
SIL1:	*Does someone from your group want to explain how you would find the number of moles of NaOH and HCl?*
Zama:	*Mass of NaOH divided by the molar mass of NaOH. The mass of NaOH was given and the molar mass is 39.9g/mol.*
SIL1:	*Yes. Once you have calculated the number of moles of reactants, what would be the next step?*
Purushen:	*You will look at the molar relationships*
Joe:	*Do you look at the molar relationship between the two reactants or the reactants and the products formed?*

SIL1: *Who would like to answer that question? How about you Amanda?*

[VD5; Lines 88-102]

In the conversation above, the SI leader embarks on understanding of chemistry concepts through probing, prompting questions, reflection, constant repetition and redirecting questions. However, she moves from one component to another during discussion which indicates that feedback has several components. These components were further reflected in the focus group interviews, in response to the question "W*hat does the SI leader do if nobody in your group can answer a question*?"

> Zamo - *SI leader asks another group to help when no one knows in our group.*
> Noma - *She also asks what do you understand by the question but from then onwards, you can say Oh! - then you realise what is actually being asked.*
> Tandi- *She asks what is given and why it is given or she asks us to refer to our notes.* [FG1; Lines 87-92]

The above conversation reveals that students recognise the different components of SI leader feedback. For example, Zamo describes how the SI leader redirects the question to another group; Noma describes feedback in terms of SI leader unpacking questions through probing, and Tandi describes SI leader feedback in terms of developing skills in answering questions, that is, first establish what is given, then reflect on why this information is given while making references to class notes.

The SI leaders' feedback is seen as an important tool for learning chemistry concepts. The above excerpts reveal that feedback is received in many forms viz. verifying the correct answer, consensus with respect to the correct answer as well as evaluation of answers and summarisation of concepts. Evaluation of answers involves asking many higher order questions according to Bloom's taxonomy (Anderson & Krathwohl, 2001). All of these instances that contribute to SI leader feedback require students to take responsibility for their learning in either revising their solutions or explanation of answers as well as feedback through reflection and evaluation of answers. It has also been found that peer feedback is also valued as a resource in student learning.

Zamo makes a distinction between SI leader feedback and peer feedback in the individual interviews [ID 8] when she claims that although she values feedback from her friends, "…*your friends might tell you something wrong or say I think that it is right but the questions the SI leader ask helps us to see why we do certain stuff and why we calculate certain things*". This statement reveals that although SI sessions are based on similar principles to study groups amongst peers, students value these sessions more because of the SI leader (expert) input.

Support is regarded as the other important scaffold for engagement in learning during the SI sessions and is described in different ways: being given information, and as support which drives the motivation to learn and which encourages engagement with chemistry concepts. The SI leader's clarification of concepts is deemed an essential aspect of support: *"…the way she explains sometimes just tops it up",* [FG1; Lines 67-68] which illustrates that explanation is a form of engagement that scaffolds learning. Another comment that signifies support provided by the SI leaders was: "..*short methods, or she shows every alternative methods of working stuff so for different people it allows for better understanding."* [FG1; Lines 65-66]

This statement is made with respect to the SI leader bringing to their attention alternative methods as well as less complicated methods of working through chemistry problems. Video data reveal that SI leaders encouraged different ideas on solving the same problem by asking the students to suggest other methods with statements such as "…*would you like to just explain the calculation in a different way".* [VD3, Line 76]

Ntombi suggests that the SI leader also assists students to *"establish a way to get your final answer through rephrasing questions".* This statement is supported by an excerpt from video data [VD 2] which reveals the SI leaders' attempts at rephrasing a question to develop an understanding of limiting reagents. This is represented by the questions: "*What would determine how much of $Fe\ (OH)_3$ would form? What would determine how much of the product will form? This is our product. How are you going to determine which one is the limiting reagent?"*[Line 241-244] These statements reveal the SI leaders' attempts to support students understanding through the use of probing questions which indicate to the students that the amount of reactants in an equation determine the amount of iron (III) oxide formed.

Other students refer to the 'direction' or hints the SI Leader gives them that support their understanding of stoichiometry concepts, such as "*she gives us a direction and through this direction we are able to understand stuff" or "she takes you half way"*. [FG1, Line 58 & 63] This direction that the student refers to is demonstrated by the video transcripts (see Appendix 7), where the SI leader has given the group a problem on determining the limiting reagent. She says: "*I want you to use the steps we have developed in answering such questions. Remember with step one, check if the equation is balanced. If no reaction is given, you have to write a balanced reaction*." [VD 5] The students seem to be guided through the problem on limiting reagents by a set of generic steps to follow and are made aware of the common errors that students make in solving problems such as forgetting to balance the equation or attempting the problem with an equation.

Other statements by the SI leaders that seem to direct the students thought processes which were derived from different video transcripts are:

> *…the question says what is the mass of the product – which means answer should be in grams…* [VD5; Line101-102]
>
> *How do we go from moles to mass…* [VD5; L107]
>
> *How did the other group explain which reagent was the limiting reagent* [VD9; L99]
>
> *What do you think is wrong with this statement and how do you correct it* [VD9; L47]

The above statements depict feedback in the form of probing questions posed to the students enabling them to reflect on their understanding of concepts. It is evident that feedback can also be regarded as a form of support.

Students constantly use the terms "*gives us", "takes you", "helps you", "shows"* and the "*SI leader explains"* to demonstrate their engagement in the SI sessions, which indicates that they are not totally aware of how they learn, and perceive learning as being given information or the responsibility for learning is solely dependent on the SI leaders actions. Only when prompted with respect to the different types of engagement experiences in the SI sessions do students actually come up with the examples of how they engage during SI sessions in developing an understanding of chemistry concepts, which is described in terms of repetition of concepts ("*she repeats stuff"),* scaffolding, exposure to alternate methods and through explanation of concepts. These are revealed in the remarks below, where SI leaders ask students to repeat explanation from other students such as "*Which one of you would like to just repeat what she said so I know that you've understood the method of solving for the masses of individual elements?"* [VD5] This statement suggests that repetition allows the SI leader to assess students' understanding of concepts. Repetition is also a form of drill for the students in developing an understanding of concepts, as seen in the following excerpt from the video data:

> SIL1: *He says that based on the stoichiometry Fe_2O_3 is made up of 2 Fe and 3 Oxygens. If you have to write the stoichiometric relationship Fe_2O_3 over 1 is equal to number of moles Fe^{2+} over 2. Therefore if you want to find the number of moles, you got to take number of moles of Fe^{2+} and divide by 2.*
>
> [VD 9; Lines 100-104]

In the above instance, repetition is used as an invitation for deliberation in the discussion of mole ratios in attempt to calculate the mass of Fe_2O_3. Support received during SI sessions is also described in the form of being given information. The excerpt below describes a student's opinion that information is being given to him and that he therefore has a better understanding of chemistry through this form of support from SI leaders.

> Francis - *I can say that the good way to understand very well chemistry you have to come to SI because where the tutors are giving everything you that you want to know in chemistry because the other things that the lecturer didn't give in SI the tutor gives us everything basically, so it is very exciting.* [FG2]

Here again, the student makes reference to a "didactic model" of learning which involves a more teacher-centred approach to learning – "*they help us to understand chemistry especially stoichiometry*". This can be interpreted from a psychological perspective as indicated in table 4.2 chapter 4 as students' specific beliefs and values. This indicates the student's belief that his mind needs to be filled with information and that he is unaware of educational theories like social constructivism, which indicate that knowledge could be constructed from prior knowledge or experiences and that we develop an understanding of chemistry concepts through knowledge construction.

This point of being supported through knowledge transfer is further highlighted by Francis when he recognises that his understanding of limiting reagents has improved by explaining the problem on the board and thereby reflecting on his understanding of limiting reagents. However, he still perceives learning as being given information: "*…the tutor told me that the way that you did it is not the way it was supposed to be done. They showed me a good way to find the theoretical yield*" [FG 2], and by not developing or constructing a better understanding for himself.

Only when prompted with respect to whether SI leaders actually give students answers does the student recognise that answers are not given at SI but rather questioning and discussion techniques are used to develop an understanding of concepts. This is revealed in the following comment: "*…they give me the way to think about for myself how to find the theoretical yield.*" [FG 2]

This statement further argues that there is a sense that students believe that someone else is responsible for their learning and they probably believe that what they know and do not know is as a result of what the lecturer or SI leader does or does not do: they have no control/ responsibility over what they learn, as depicted by the following remarks: "*They give us some worksheet and some knowledge.*" It is interesting to see that the student views being given a worksheet as a gain in knowledge for him rather than a means to develop a better understanding of concepts. Students also acknowledge support they receive in SI in the form of more time to engage with a concept and scaffolding of the learning process: "*I think they give us more time to solve exercises and when we are going wrong they help us*."[FG2]

Ways in which SI leaders support students during the SI session are further illustrated by the individual interview data which indicate that support plays a vital role in encouraging students to engage with chemistry concepts, as SI leaders are always willing to assist: "*…she doesn't ever turn us down, which has helped me a lot*".[ID6] This comment suggests that the student benefits from the support structures that the SI leaders offer with respect to supporting engagement in learning with hints, getting students to reflect on their understanding through questioning techniques and guided inquiry. This is evident in the following comment made by Nivashni in the individual interviews: "…she *gives us a hint or a guideline towards getting the answer*". [FG1]

Both SI leader support and peer support are viewed as vital components to learning with respect to focus groups interviewed as well as individual interviews. This is depicted by the following statements:

> Nivashan – *In SI there is always someone there to help you out even when you are wrong; the SI leader is always there to bring to your attention where you went wrong and why it's the way it is or when in our group discussions we correct each other.* [FG1]

Nivashan's comments suggest that students value the support they receive at SI with respect to knowledge construction, irrespective of whether it comes from the SI leader or their peers. During the individual interviews, Zamo claimed that she did not quite understand limiting reagents at the beginning because she was unaware of how to determine which reagent was in excess and thus the limiting reagent. She found consulting with her friend in a group extremely useful when she would ask "*…again why did we say this? …then she would remind me*". This comment suggests that peer support can be considered as valuable scaffolds for learning.

Students also refer to the support they receive with respect to receiving additional learning material which is evidenced by the comment: *"…I like the fact that it actually improves your understanding like for instances we getting new notes and stuff which is an added bonus to us, to what we have in class".* [FG1] These remarks clearly indicate that the student values the additional support material received in improving her understanding of chemistry concepts.

There is clearly a link between motivation and the support the students receive, as represented in the follow excerpt:

> Francis –*It means that if there is something that you fail before so you found some place where someone can explain you better and you come to understand something better, so if that thing scares you can be able to understand it so it's giving you motivation to come every time and everyday to learn more because it makes you understand better*. [FG2]

This student seems to get his motivation from a belief that the support he receives in SI gives him a better understanding of concepts and he no longer feels intimidated by what he does not understand. His view on learning, however, does not indicate his contribution to the learning and he believes in the 'received view' of learning with comments such as "*someone can explain you better*".

The discussion above indicates a significant relationship between how student engage and how they learn. SI leader feedback and support as well as peer support are deemed essential components in developing an understanding of chemistry concepts. Students' own understanding of how they learn does not reflect taking responsibility for learning but rather reflects receiving dignified support. It is evident that the SI leader as well as peer feedback and support are regarded as scaffolds for the learning of chemistry concepts.

6.2. 2. Reflecting on understanding of concepts

The way students develop an understanding of stoichiometry concepts through reflection was considered another important category of description with respect to student engagement in chemistry SI. This was evident through the SI leaders' probing, asking students for explanations, modelling evaluation of concepts, summarising concepts learnt and drawing concept maps.

The focus group interviews reveal that the chemical engineers and other engineers recognise that reflecting on certain stoichiometry concepts in order to be able to explain the concept in their own words, develops a better understanding of these concepts. This is represented by remarks such as "*…when you explain in your own words, your understanding of that section you, know it you understand it or not."* This implies that students get to assess their understanding when asked to explain concepts and it also offers opportunities for clarification of ideas, as suggested by the excerpt below:

> Nivashan - *If your answer is wrong it is not a problem as long as you know where you went wrong and how to correct it.*[FG1]

These students recognise that learning is not about right answers but rather being able to reflect and revise how one understands concepts. It has been found that students learn to model the SI leader's behaviour in asking questions such "*What do understand by that concept?" or "Why have you made that statement?*" This idea is revealed in the following excerpt:

> Mbonga - *SI promotes you to question what we are told - the more you question, the better you understand. You don't question just for criticism but rather you want to know how to improve your understanding*. [FG1]

This student suggests that he needs to question to gain clarity and to develop an improved understanding of concepts. Modelling SI leader behaviour with respect to reflecting on understanding of concepts is viewed as a valuable tool with respect to unpacking problem statements, as revealed by the comment "*…it's like the same question I'm gonna ask myself when I see a problem. Why is this given*?" [FG2]

This student suggests that she models the SI leader's questioning techniques in answering problems where she firstly writes down what is given and asks herself why is it given in relation to what is required to be calculated.

Closely associated with questioning for understanding is evaluation of concepts, which is also considered a useful task in developing a better understanding of stoichiometry concepts. This is evident from the following remarks:

> Zamo - *We get to evaluate our answers because she asks questions such as – why did you work with this method? Or how did you get that answer or what was the purpose of doing this? Or why are these given?* [FG1]

Zamo recognises that learning involves evaluation of concepts for understanding. These questions seem to get students to reflect on their understanding in an attempt to develop a better understanding of concepts. Other students describe the different ways in which the SI leader initiates reflection which enables them to evaluate their answers, as portrayed by the following comment:

> *If someone has a different answer she gets them to put it up on the board so that we can evaluate the answer.* [FG1; Line 196-197]

The student above indicates that verification of answers is yet another form of feedback or is closely aligned to feedback and is important, as they get to evaluate their answers in their groups or through class discussion. Evaluating other students' answers is also believed to "*develop a better understanding for me",* as expressed by one student. Besides evaluating their answers and other students' answers, students also get to reflect on the different methods used in arriving at the same answer and in a way evaluate which method they understand best, as reflected in the following comment:

> *There is never a set way of approaching a question, there are a lot of different methods and SI enables us to choose and evaluate which methods are best for us to understand and not just what is given.* [FG1; Line215-218]

This student recognises that there is never a single method of approaching a question and the SI discussion and engagement enabled him to evaluate the different methods being discussed and to choose the method that made the most sense to him. This suggests that there is a link between reflection on different approaches and understanding. The student believes that one learns more when "*you try to teach something to someone - so that helps like you learn better*" [FG1; Line23-24]. He further explains that sometimes after a lecture "*…you think you know a concept but then you get to SI and somebody asks a question and you are totally stumped with respect to the answer*". His argument is that you only realise if you understand a concept if you are able to teach it to someone else, in other words, if you can reflect on your understanding of that concept.

This student clearly shows signs of being aware of how he learns best, which is being able to teach someone else. This meta-cognitive awareness is further represented by the another student [FG2] who claims: "*I think that when you get into a discussion and explain to the class how to solve a problem you understand more than if you just do it quietly, so when you explain to people that is when you figure out if you understanding it and if you are going wrong you have people to help you."* This student is aware of how she learns and goes on to explain that if you understand a concept then you will be able to explain it to the class. She in addition understands that learning does not involve just giving the right answer but rather receiving feedback with respect to your understanding.

> Amanda - *"SI gives you an opportunity to question why is that answer right why is my answer wrong? You learn from that because you pick up stuff from other people, other peoples methods".* [FG2; Line 84-86]

This student suggests that SI sessions give her an opportunity to reflect on her understanding of concepts by asking higher order questions which require analysis and evaluation of concepts. Other students comment that "*…once you thought about something for yourself it is not easy to forget it*" [FG1], which also suggests that reflection develops understanding and *"…if you're just given a solution you will not remember or understand how it's being done but if you do it on your own you understand better*" [FG2]. These statements from the focus group interviews reveal that students are aware of how they learn which involves developing an understanding of concepts through reflection.

The engineering students demonstrate that they are aware of the difference between memorising information (studying) and “learning” which involves understanding of concepts. Praveena sums up her experience of SI engagement by indicating that SI activities assist her in reflecting upon her learning with the following comments:

> *At SI there’s a whole lot of other people there so they come in with different questions and different angles of thinking and for example if there is something that you feel that there’s a set method in which to calculate, some other person might have a completely easier and different way to that, it saves you time….most probably their method is less time consuming or however you may think you know something but in actual fact you don’t understand it until you really go through it with other people and you get this whole new perspective. In that way you know that you have certain problem areas and it can help you in that way*. [FG1; Line 19-26]

This student displays a sophisticated understanding of engagement which indicates that SI learning engagement allows her to reflect on her learning experiences in different ways viz. through asking different questions, being exposed to different ways of solving problems, as well as gaining clarity with respect to her understanding of chemistry concepts. Lastly, students suggest that they also reflected on their understanding of stoichiometry through SI leaders introducing them to a method of “*writing all concepts learnt in a concept map*”, which allowed for the formulation of links between different aspects of stoichiometry such as limiting reagents, empirical formulae and percentage composition.

The discussion above reveals that a significant amount of the engineering students are unaware of how they learn however; most of them value the opportunities for reflection offered by the SI learning spaces. It is therefore argued that students need to be given opportunities to reflect on their understanding of chemistry concepts in developing meta-cognitive learning skills so that students can constantly assess their understanding of concepts and preferred learning styles.

6.2.3. Personal Drive / Motivation

A personal drive or motivation to learn featured as a category of description with respect to relating how the engineering students learn in chemistry SI. Students reflected during the focus group interviews that motivation played a fundamental role in inspiring them to learn, which is represented by the following excerpts:

> Nelli - *It is like when you like something you want to spend more time with it and keep on doing or practising it.* [FG1; Line142-143]

Nelli has another take on why she is motivated to study chemistry more than other subjects: she describes her predilection for the subject with respect to giving more time and practice to something you enjoy doing.

> Akash - *The way SI is carried out or the way SI is organised, when we come to SI we have a feeling of wanting to learn and as a result your mark is boosted because of the knowledge gained during the SI session.* [FG2; Line4-6]

This student is motivated by different learning styles offered by the SI sessions which in my opinion, probably refer to collaborative learning styles. He further recognises that motivation to learn is linked to the learning that takes place.

Joe in contrast, is motivated by the solutions to problems he receives at SI where he is able to reflect on his understanding of concepts: "*…it wakes up your mind and motivates you after you have been failing - you realise where you went wrong and you get some solutions*". [FG2; Lines 112-114]

The following students are motivated to take responsibility for their learning because they are aware of the vast content that is covered in class and are either overwhelmed by amount of work to be covered or feel that they can only achieve the learning with support and guidance.

> Mbonga - *I think that if there was no SI for chemistry I would really struggle…like for chemistry there are a lot of notes ...*
> Nelli -*... sometimes there is not enough time to go and consult with the lecturer.* [FG1]

Mbonga and Nelli display a sense of motivation to attend SI sessions because they feel that they cover loads of content in class and are unable to clarify concepts with the lecturer because of time constraints in the lecture. SI sessions thus give them an avenue to address these problems.

It is evident that motivation plays a significant role in chemistry SI by encouraging engagement with difficult stoichiometry concepts, thereby increasing students' confidence through collaboration and support.

6.2.4 Developing an understanding through Practice

The Chemical engineering module had an additional category of description in the analysis of the focus group interviews with respect to their understanding of how they learn. This is represented as developing an understanding through practice or developing an understanding by working through many examples. It is evident by the following claim: "*…the questions are much tougher than our tuts – so when we get to a test we are not like surprised when we find something new."* [FG1] This statement reveals that students get to practise challenging problems in SI in preparation for the test or exam.

This point is further emphasised by Duduzo, who states that "*you learn more from SI than from the lecture, you get more practice and your questions get answered"* [ID 7]. This comment reveals the interactive nature of the chemistry SI sessions which lends itself to students engaging with different examples by getting more practice and where the collaborative learning styles allow students the opportunity to clarify chemistry concepts.

Thuli, who is a chemical engineering student, argues that practice is significant in developing understanding of stoichiometry concepts: "*…if they reverse the question, you get confused and you think that you don't know what is going on, but actually you did not pay attention by practicing in SI"* [FG1]. This point is further explained by Nelli, who suggests that she gets exposure to different types of questions in SI as a means to improve her understanding of chemistry concepts:

> Nelli - *Allows you to go through the experience of answering questions and if you understand the concept you don't have to "by heart" stuff and you can answer any question.* [FG1; Lines118-120]

These students understand that learning involves practising through many examples in developing a better understanding of concepts. In contrast, Amanda recognises that learning involves practice but does not want to take the responsibility for the learning by trying to figure out the problems for herself. She prefers to attend SI where she feels that everything is explained to her. It is possible that she values the support she receives from peers and the SI leader, which gives her the confidence to attempt the examples. She is aware that learning is a social endeavour that involves collaboration, reflection and sharing of ideas or information amongst peers:

> *I think that SI was good for me because during lectures, the lecturer goes through the work but he does not do lots of examples and stuff and we have to go home and try to figure it out for ourselves but when we come here it is explained properly the formulae's and everything is explained in detail and we get to learn from other students because students are given an opportunity to explain which is very helpful.* [FG2; Line7-12]

Motivation to engage in learning chemistry concepts is found to be triggered by several aspects viz. through collaborative learning experiences, different learning styles, the need to take responsibility for their learning, encouragement, feedback and support and lastly, through developing an understanding through practice in answering different types of questions.

6.3 Social Learning Engagement

Social learning engagement was the second broad theme that was derived from the focus group interviews. It was found that social engagement does different things in the learning process. What will be described is how social engagement operates in motivating learning, how it contributes to collaborative learning and lastly, how opportunities for social engagement developed confidence through understanding.

Students viewed social engagement with respect to the following categories of description: learning chemistry can be enjoyable, collaborative learning engagement, and opportunities for social engagement developed confidence through understanding.

6.3.1 Learning Chemistry can be enjoyable

Learning chemistry during SI was regarded as an endeavour that brought about much enthusiasm and enjoyment amongst students. One student's description of his experience of engagement during SI sessions was that it was inspiring, as he believed that his understanding in a sense increased because of the support he received from the SI leaders as well as the enjoyment he experienced in learning.

> *Engaging in SI sessions boosts our understanding of chemistry. The tutors are very supportive and your experience at SI is one not to forget. While learning we also have fun- so it makes us to want to learn chemistry because coming to SI is quite exciting.* [FG2; Line1-3]

This student refers to the social aspects of learning by associating it with being fun. He refers to the support received by tutors but does not say what actually makes the learning fun. Zamo, in contrast, explains why she thought her experiences of SI engagement were fun:

> *We get to work with many people and they have different ideas and so we also get to learn how other people think. So that's my definition of fun. Sometimes*

you can't do your things on your own - you know something about the question and someone else knows how to start then someone in the group assists you because they know and we carry on from there. We assist each other actually.

[FG1; Line 76-81]

This student associates 'fun' learning in chemistry SI as a social endeavour rather than an individual task that involves knowledge construction through various inputs, collaboration and forms of support.

The discussion above reveals that learning in chemistry SI is regarded as a 'fun' learning experience through collaborative learning engagement, exposure to a diversity of learning ideas and the support that is received in learning.

6.3.2. Collaboration

Students' collaborative learning engagement was described in several ways: firstly, they recognised that learning is a social endeavor which developed a better understanding of concepts through exposure to different points of view. One student said: "*…while I was working in a group I found that what I knew was not better than what others knew so it is better to work in a group*" [FG2]. This point is further emphasised by the following excerpt:

I feel that one of the good experiences are that you get to work in groups and with different people which really clarifies your understanding of chemistry concepts because people might really have different views, methods or ways of working out stuff and ..so in that way I think it clarifies chemistry concepts.

[FG1; Line12-16]

This student seems to value group work or collaborative learning as she believes that the variety of input received during group discussions has improved her understanding of chemistry concepts. These sentiments are further emphasised by Mbonga, who states that the "*explanations received during collaborative learning have also been good*" [FG1].

Group discussions also seem to serve as a means of revision, as indicated by one student, who remarks: "*If you talk to each other you find out that, oh you forgot this and tend to remember things you forgot*" [FG2; Line96-97].

Working in collaborative groups during SI sessions appears to expose students to different ways of answering a question. This was described as motivation for learning, as discussed earlier in this chapter. The following excerpt describes Angel's experiences of collaborative engagement:

You find that when you work on your own you sort of use that same methods but when you come to SI like you find other methods used by people which are much easier than the one you were using in that way you benefit. [FG2; Line31-33]

This student values collaborative engagement because she gains exposure to different methods used in problem solving, which she views as beneficial in clarifying her understanding of concepts. The discussion thus indicates that collaborative learning has many roles which are represented by developing a better understanding of concepts through exposure to different points of view, and explanations which are useful and also serve as a means of revision of concepts. It can therefore be concluded that collaborative engagement allows students an opportunity to learn from each other, as suggested by Akash in his individual interview: "W*e definitely learn from other people*" [ID2].

The following students describe how group or paired problem solving increased their confidence in attempting to answer questions during class discussions in chemistry SI sessions:

> *If you discuss the answer in a pair you feel more sure of your answer than if you* ... [FG1]
>
> *Discussing in pairs first helps in answering in front of the class.* [FG1]

> *If you know each other you feel more comfortable and it is much easier to talk and go up to the board.* [FG2]

These students ascribe their increase in confidence to the collaborative and interactive engagement styles used in SI sessions, which encouraged discussion and participation and developed a sense of familiarity with other students in the class.

This point is highlighted by Thuli who claims: "*I find it easier now to approach people if I have a problem because I know that everyone here wants to learn*" [FG2]. This student now finds it easier to ask questions with respect to developing an understanding because she has come to the realisation that everyone at SI wants to learn or is there to learn and does not feel intimidated to ask questions.

Akash mentions in his individual interview that "*the effort that we put into group discussions makes us feel good even if we come up with solutions that sometimes might be wrong*" [ID 2]. This comment suggests that collaborative engagement allows students an opportunity to construct a shared understanding of concepts which gives students a sense of confidence rather than having no idea of how to attempt the problem.

Mbonga in contrast revealed that he feels that collaborative learning is not always good for him: in some instances when he cannot contribute towards the right answer, he becomes frustrated and has negative feelings towards group work, as depicted by the following remark:

> *Group work not always good - because sometimes if you don't have a clue of what is happening, you end up asking and asking you feel a bit silly and like the silly person who doesn't know anything in that group.* [FG1; Line84-86]

This student shows a lack of understanding of the meta-cognitive skills required in learning and is more fixated on knowing the right answer rather than developing an understanding that contributes to knowledge construction through discussion and support.

It is evident from the excerpts above that collaboration engagement and discussion amongst peers seems to develop a sense of confidence which motivates the engineering students' ability to learn from each other. There are, however, other opinions that collaboration is not always successful but is seen to develop negative emotions amongst students who feel that they have nothing to contribute to the discussion.

6.3.3 Opportunities for social engagement

Students in this study believed that the opportunities created during SI sessions for social engagement provided feedback that improved their understanding as well as their confidence in sharing answers. Students describe the different ways in which opportunities were created during the SI sessions for social engagement amongst students and the SI Leader in terms of "*she asks us to explain in our own words and usually uses the feedback thing where she asks what do you understand by that question?"; " the SI leader asks another group to help when no one knows in our group", or" she also asks what do you understand by the question… then you realise what is actually being asked"* and *""she asks what is given and why it is given or she asks us to refer to our notes*" [FG1].

These questioning techniques are portrayed as opportunities created for engagement during SI sessions in developing a better understanding of chemistry concepts. This reflects the students' understanding that the process of learning is more important than the product. What also comes through is the fact that this student values the feedback or support received from other students and the SI leaders. However, it would seem that some students still focus on the product of the exercise which is evident from the individual interview with Nivashni, who states that she will only go up to the board to explain a concept if she is confident that she has the correct answer: "*I would go up to the board but I mean it depends how confident I am about my answer"* [ID6]. This statement indicates that students' confidence is influenced by their understanding of chemistry concepts. She goes on to explain: "*I do feel comfortable and safe and stuff there but if I know for sure my answer is wrong I wouldn't…..I'd let someone else do* *it and then I can correct my mistakes and know where I went wrong",* which indicates that the SI learning space encourages varied degrees of confidence with respect to learning engagement and it influences peer engagement when students' lack confidence in their understanding of concepts.

Zamo in contrast reveals in her individual interview that "*if you're explaining to other people you feel like I'm superior, I know the stuff and you feel more confident*" [ID8]. This comment further supports the finding that the SI environment encourages different levels of confidence with respect to learning engagement which is dependent on students' understanding of chemistry concepts.

Students have also indicated that collaborative learning techniques offered in chemistry SI have assisted in increasing their confidence in contributing to explanation of concepts in their own words:

> *…she'll give us a specific problem….we'd all answer it and we compare our answers and we see that it's right and then you get confident knowing that someone else also has the same answer as you so I mean its' confidence that maybe you answer is right but even if it isn't, you are corrected there and at least you learn from your mistakes"* [ID 6; Line 44-48]

However, only when prompted with respect to the different types of social engagement opportunities experienced in the SI sessions, do students actually come up with the examples of how they engage during SI sessions in learning stoichiometry concepts. As mentioned previously, this in a sense reveals that not all students are aware of how they learn or their meta-cognitive learning skills have not been developed.

These different opportunities for social engagement are valued by students, as depicted by the following excerpt:

> *…in lectures we do not necessarily have the time to go over the notes but when you go over the notes with another person I find that you understand better".* [FG1; Line93-95]

This student describes how collaborative discussion of lecture notes improves his understanding of chemistry concepts through scaffolding. In this case, the student indicates that SI provides opportunities for revision of lecture notes which assists in the learning of chemistry concepts. Students also illustrate that collaborative learning techniques such as paired problem solving create opportunities for engagement: "*…she also pairs you and when paired with different people you become more comfortable around different people*" [FG1]. This student further explains that these collaborative techniques encouraged student engagement by creating a more relaxed environment where students were familiar with each other. This is believed to break barriers to engagement in the SI sessions.

In contrast, some of the students do displayed an understanding of the different meta-cognitive skills required in developing an understanding of chemistry concepts. This is represented by [FG 1] as follows:

> **…** *She allows you to speak in groups but she does not leave you hanging and she verifies your answers*
> *She gives one person an opportunity to explain the way they understand it.*
> *Everyone is involved in the activity it's like not you alone or you and your partner are not the only ones involved in the discussion.*

Students therefore indicated that opportunities for social engagement were created by the SI leader who developed an understanding of chemistry concepts through feedback (verifies your answers), explanation (gives students an opportunity to explain), and the use of collaborative learning techniques (everyone is involved in the activity). Social engagement was experienced as a fun way of learning: it created collaborative learning opportunities, developed confidence through understanding and created opportunities for feedback.

6.4 Strategic Engagement

Strategic engagement is framed in terms of the ways in which students develop strategies for engaging in chemistry SI. Students described their understanding of taking responsibility for learning using the following categories of description: planning and preparation, responsibility for the learning versus support/disengagement, and developing a culture of responsibility.

6.4.1 Responsibility for learning

As will be discussed the data reveals that there are clearly advantages to taking responsibility for learning through engagement with chemistry concepts. However, it is Vygotsky (1978), who also emphasised that scaffolding of the learning improves understanding. The following categories of description emerged from the data with respect to students' understanding of taking responsibility for the learning via developing a culture of responsibility for learning through planning and preparation, support, and student disengagement.

6.4.1.1. Developing a culture of responsibility

Students described how planning and preparation for SI sessions played an important role in how they engaged and took responsibility for their learning at chemistry SI. This is revealed by the following comment from the focus group interview: "*I think if someone has a problem they should go submit it to the SI leader before the SI session so that we will come prepared and she comes prepared with maybe some extra notes for us. This will make more time for the session*" [FG1]. This describes the students' recognition that planning and preparation for SI sessions enhance the input he might receive during SI sessions. This student suggests that being aware of the questions to be discussed in advance might increase session time for more examples to be covered. However, it is still evident that this student is more focussed on the products received at SI rather than the process of developing an understanding of stoichiometry concepts.

This student is aware that he should take responsibility for his learning by preparing for SI sessions. He also shows a commitment to taking responsibility for finding out in advance what he does not understand. However, he sees his success in the SI session as solely the responsibility of the SI leader in preparing notes for him rather than the SI leader being aware of the agenda for the SI session and arriving prepared to guide the learning process.

Other students displayed a sense of taking responsibility for their learning which is supported by the following statement from the focus group interview:

> *Actually you feel like for the next SI I need to do this and I have to be prepared and you start preparing by doing other examples…* [FGI; Line130-131]

When prompted with respect to why she feels the need to come prepared to SI sessions, the student remarked: "*I want to find out more and more and have questions to ask at SI. I want to practice more*". This student clearly appreciates the value of preparation for SI sessions in attaining maximum benefit from the sessions.

It is evident from the excerpt that the students describe the SI sessions as means to motivate them to engage more with chemistry content as they are aware that they need to prepare for the sessions so that they can reap the most benefit from them with respect to clarifying what they do not understand. Engineering students' need to prepare for SI sessions is further supported by the following excerpt:

> *I don't want to come here and look all stupid because you don't know your work so you want to go home and do something and come with your problems so you can get help and be able to help others because in helping others you also learn so it motivates you quite a lot.*[FG2; Line 99-102]

This student recognises that taking responsibility for her learning by being aware of the concepts she does not understand before attending SI could assist her SI experience. She therefore prepares in advance for the sessions and also believes that if she comes prepared then she can assist other students which develop confidence and motivation in her own learning. She is aware of how she learns and recognises that by teaching other students *("I learn to understand the concepts even better"),* she can also develop a better understanding of concepts in the process, which motivates her to learn.

The engineering students are aware that they need to take responsibility for their learning, as demonstrated by the following excerpts:

> *She doesn't like spoon-feed or give answers; you need to work it out yourself so you can understand it better.* [FG1; Line56-57]

This student is aware of how she learns, which involves attempting the problem first on her own. She goes on to explain that this method of attempting a problem first on your own, "*actually coaching your mind to think for yourself instead of watching someone else work out the problem",* is a helpful method of engaging with content as a means of training your mind ("coaching") to think or construct knowledge.

Another student describes how he believes that he has taken responsibility for his learning by attending SI sessions because he has not studied chemistry in a while ("*I can't remember when I last was doing chemistry")* and was finding the lectures difficult to understand. He remarks that SI has allowed him to understand and remember things that he had forgotten through discussions in the SI class. Other students claim "*they are trying to make us to work by ourselves"* which implies that they are aware that SI develops skills in encouraging students to take responsibility for their learning.

When asked what the SI leaders do to facilitate a discussion, the following response was received:

> *Let's say I have got a question about finding the moles, instead of the tutor just telling me the equation n = m/ M they will ask someone in the group for an answer.* [FG2; Lines69-70]

Only when prompted with respect to the SI leaders' facilitation skills do students mention the questioning techniques that are used to develop an understanding of concepts. In most instances, Focus Group Interview 2 is revealing, as it represents the other engineering students who talk about the SI leader giving them information. It is very interesting to note that methodologically there have been very few instances observed where the SI leader has given students information; however, students' perceptions of learning implies being given information. This is further represented by the excerpt below:

> Francis - *They ask you questions which lead us to the answer.* [FG2]

This student is aware that the questions asked during discussions in SI allow them to develop an understanding of the concepts. His view on learning however, indicates that he believes that the SI leader directs or supports him towards the knowledge rather than facilitates the learning of concepts through questioning.

Joe in contrast, is aware that engagement in group discussions has some benefit for him.

> *We learn more from a discussion because they can just give you the answer without showing you the method they used to get the final answer and you will not understand better than if you were discussing in a group so I think working in a group is the best way to understand properly.* [FG2; Line 92-95]

It is evident that he values the support he receives from his group in arriving at the answer as he claims that just being given the right answer does not result in learning; it does not seem like he wants to take responsibility for the learning because he goes on to say that "*you need to be shown the method used to ensure that you understand the concept*". So just being given the final answer to a problem does not work for him probably because he has difficulty developing an understanding of the chemistry concepts, being a first language French-speaking student. It is evident that listening in on a group discussion has more benefit for him because other students are involved in generating an answer through collaboration, which he believes makes more sense to him than the final answer. This implies that he values learning the process more than being given the answer or the product.

Other students are motivated to take responsibility for their learning after attending SI since they now have a better understanding of chemistry concepts and are able to study more effectively at home and also are aware that they have some avenue to consult with respect to their difficulties.

> *What gives motivation is that we have the facility to understand and study better at home by checking your notes easily and you find something wrong also you can say no I find this difficult ....* [FG2; Line104-106]

It is therefore argued that skills developed during chemistry SI have the potential to develop a culture of responsibility for learning through engagement in activities that motivate students, develop critical thinking skills through questioning techniques, develop meta-cognitive skills through planning and preparation and lastly promotes discussion of concepts.

6.4.1.2. Support

The following student recognises the need to take responsibility for learning. However, she also values the support that she receives from her peers and SI leader which probably shapes students' understanding of how they learn, as discussed earlier in the chapter.

> *I think that SI was good for me because during lectures, the lecturer goes through the work but he does not do lots of examples and stuff and we have to go home and try to figure it out for ourselves but when we come here it is explained properly the formulae's and everything is explained in detail and we get to learn from other students because students are given an opportunity to explain which is very helpful.* [FG2]

This student recognises that learning involves practice but does not want to take the responsibility for the learning by trying to figure out the problems for herself. She prefers to attend SI where she feels that everything is explained to her. She probably values the support she receives from peers and the SI leader. This student also shows an understanding that learning is a social endeavour that involves collaboration, reflection and sharing of ideas or information amongst peers.

Peers are also regarded as resources, which is explained by Akash in the focus group interviews: *It also saves time, let's just say for instances if you are stuck on a question and then you can go consult with your group and you find an answer or a method of finding an answer than sitting with the question and not going anywhere*".

[FG2]

This student views his peers as a resource and believes that he takes responsibility for his learning by consulting with them with respect to problems he encounters.

The discussion above indicates that students are aware that they need to take responsibility for their learning but also deem the support they receive from peers and the SI leader as beneficial to their success in the course.

6.4.1.3 Student disengagement

When asked if all students participate and contribute to group discussions, students indicated that most of them attempt to contribute; however, despite the non intimidating environment there are a few students who disengage through their lack of confidence in contributing the right answer, which is evident from the following remark: "*…some of them are rather shy and quiet but there are a few of us who do always participate in the discussions"* [ID6]. This statement indicates that the discussions are in some instances dominated by students who are more confident in answering questions or contributing to a discussion. Nivashni indicates that one of her friends is very shy but "*he does benefit from the sessions as well because he understands his work when the SI leader asks him to respond to a question*". This statement indicates that this student is accustomed to the ‘received’ view of knowledge, which is typical of the didactic lectures offered to engineering students in chemistry and can be attributed to several reasons, ranging from lack of suitable infrastructure to large class sizes.

Another form of student disengagement with problem areas in stoichiometry that was evident during the individual interviews was the fact that many students did not take questions to SI that they were experiencing problems with but rather said “*it was too late*” [ID 2], meaning that the topic was already covered or that something similar had been done already, as in “*I think we did a similar example at SI*” [ID 3]. It is apparent from these comments that some students merely relied on other students’ questions or the SI leaders’ activity worksheet for that session to clarify chemistry concepts.

The data discussed reveal that the engineering students are strategic with respect to engaging in chemistry SI and taking responsibility for the learning. Support and motivation are regarded as integral parts to developing students’ confidence in taking responsibility for their learning. This is demonstrated by students who claim that SI inspires them to prepare for future sessions. Students who are accustomed to the didactic lecture disengage in chemistry SI as they are more focused on the products of the SI engagement rather than developing an understanding through the process.

6.5 Conclusion

This chapter reveals how engineering students engaged at chemistry SI making use of the three themes derived from the data. Firstly students were found to engage experientially through feedback and support, development of understanding through reflection, motivation to learn and development of understanding through practice. Literature has long reflected the importance in first year studies in providing quality, timely feedback to students, both formally and informally (McInnis, James & Hartley, 2000 and Ramsden, 2003). Kift & Field (2009) mention several case studies that demonstrate a strong commitment to the provision of a variety of feedback to students as a means of motivating deep student learning as well as the provision of ‘rich’, detailed, regular and progressive feedback as a motivating factor for student engagement. The feedback the engineering students receive with respect to individual and collaborative attempts at learning seems to be valued as an essential component that contributes to their learning. Feedback and support are vital for knowledge construction according to the social constructivist theories of learning (Vygotsky, 1978).

The second theme, social learning engagement, revealed the following categories of description: learning chemistry can be fun, opportunities for collaborative learning and opportunities for social learning engagement. "From a social constructivist perspective, deep understanding is dependent not only on exploring values and having social interaction, but on engaging all other aspects of the person as well, including attitudes, emotions, aesthetic experience and behaviour", according to Leithwood, McAdie, Bascia, & Rodrigue (2006:12). It is from this perspective that engineering students' views on their experiences of how they engage during chemistry SI sessions was sought, and is being examined in this dissertation.

Socio-constructivist theories confirm the importance of community and interactive forces to motivation, which in turn link effective teaching with modes of delivery that promote engagement and discussion (Cannon, 1988), particularly in ways that encourage active and equal participation. Motivating approaches to pedagogy can also be considered important from the perspective of responding to the diversity of students' learning styles and preferences. Collaborative activities can assist to promote deeper levels of knowledge generation (Felder, 2003), as well as develop initiatives and higher order thinking (McLoughlin, 2000). Lastly, strategic engagement generated the following categories of description: developing a culture of responsibility, supporting engagement and student disengagement. These categories of description reveal the strategic ways students engage either in developing responsibility for learning, supporting engagement or disengagement in the learning of chemistry concepts.

Although this chapter theorises how, when and why the SI programme works during chemistry SI, it is the intention of this study to theorise how the engineering students engage in chemistry SI in developing an understanding of stoichiometry concepts. Therefore, the next chapter will make use of engagement theory to theorise the various ways students engage in chemistry SI in learning of stoichiometry concepts.

CHAPTER SEVEN

EMERGING THESIS IDEAS: BEYOND LEARNING THROUGH ENGAGEMENT TO SOCIAL LEARNING ENGAGEMENT

7.1 Introduction

This study has focused on how and why first year engineering students engage in chemistry SI sessions and in particular with stoichiometry concepts in chemistry, in the way that they do. Chapters Five and Six of this study have attempted to answer how the SI environment influences engagement and how first year engineering students engage in chemistry SI environment respectively. This chapter theorises about students' engagement with stoichiometry concepts in chemistry SI by borrowing from the ideas of Kearsley & Shneiderman (1999) and their model on engagement theory, which is used to drive the emerging thesis. They argue that engaged learning occurs in settings which involve active cognitive processes such as creating, problem solving, reasoning, decision making and evaluation, which coincide with the insights of this study.

Data from my study suggest that students get to know what they know in stoichiometry firstly through **relating**; this notion of relating comes from orientating themselves to chemistry generally and to the subject of stoichiometry specifically. In terms of the data, this is evident in motivation, the idea of authentic consensus, collaboration, management of group dynamics and social skills development. Secondly, an authentic focus is created by SI leaders to enable spaces for social learning, which includes **creating** necessary spaces through different means such taking up opportunities for engagement, responsibility for learning and opportunities to learn. Lastly, it is by means of **reflection,** evident through the data in terms of collaboration, feedback and the nature of the support the students obtain during SI sessions. Another dimension to engagement theory is therefore being proposed, and the model is extended to include social learning space, which was derived from the data to explain how students engage in chemistry SI. In order to move beyond the engineering students' engagement in the SI social learning space, the notion of

Phenomenon of space is used to theorise how students get to know stoichiometry concepts in chemistry SI.

The chapter is divided into two broad sections. The first section analyses students engagement with stoichiometry concepts in chemistry SI, while the second section theorises students' experiences of SI engagement.

7.2 Students Learning Engagement

The notion of engagement in this study is driven by 3 imperatives in terms of engagement theory: **relate, create** (borrowed from Kearsley & Shneiderman, 1999) and **reflect** which I have drawn from others such as Leithwood, McAdie, Bascia, & Rodrigue (2006) as discussed in Chapter Four, section 4.4.2. Given that engagement theory builds on the issue that students must be meaningfully engaged in learning activities through interaction with others, it is not surprising that the data in this study speaks to these issues in a similar manner.

7.2.1 Relate

In this study the principle of 'relate' is demonstrated in group and peer discussions (communication) prevalent during SI sessions, planning, and preparation of tasks students embark on in order to establish what they know or do not know with respect to chemistry concepts. This includes the management of group dynamics regarding receiving feedback from peers, social skills development in terms of group and peer discussions and explanation of chemistry concepts after group discussions. It is found that communication, planning and preparation of tasks, management of group dynamics and social skills development are all negotiated by the social learning spaces created by the SI leader during SI sessions.

Social learning spaces created by the SI leader for student exploration of stoichiometry concepts led to opportunities for students to engage in scientific discussions with each other, and initiating opportunities for engagement for themselves and the SI group as a whole in scientific inquiry beyond learning through engagement, to social learning engagement Students were able to reshape the curriculum by bringing the results of their informal problem solving experiences forward for consideration by the whole class. These opportunities contributed to students demonstrating their competence in talking science and in particular their understanding of stoichiometry concepts.

Further, motivation derived from collaborative efforts was considered an essential aspect in communicating team efforts and arriving at authentic consensus:

> *Discussing in pairs first helps in answering in front of the class.* [FG2]
>
> *I am more confident that my answers are correct or I am close to the correct answer, which is a confidence booster and I am more confident to explain my method of answering the question.* [FG1]

Most students described their experiences of group or peer discussions as inspiring and motivating learning engagement whereas authentic consensus was derived from the socio-scientific norms developed by the SI leader as described in the methodology chapter.

A sense of confidence amongst students is derived from being able to compare and clarify understanding of chemistry concepts:

> …*we all answer it (problem) on our own and we compare our answers and we see that it's right and then you get confident knowing that someone else also has the same answer as you*… [FG1]

The idea of team efforts that emphasise communication in engagement as suggested by Kearsley & Shneiderman (1999), where students are forced to clarify and verbalise their problems, thereby facilitating solutions, is in keeping with the data from this study which suggest that communication in collaborative teams enhances learning engagement. The latter is achieved through peer and SI leader support and is perceived as instrumental in motivating learning engagement

Analysis of SI leaders discursive practices make for interesting comparisons with other studies of teacher discourse. Russell (1983) and Carlsen (1997) described the role of the teacher as that of being "in authority" as manager of classroom practices and "an authority" of science knowledge In this study, SI leaders takes up these roles in ways that promoted the sharing of these roles with the students in the classroom. As the person "in authority", the SI leader modelled ways of drawing from students to share the role of being "in authority" where they redistributed talk during science discussions by inviting students to offer their ideas and interpretations even after an initial answer had been given. In these ways, SI leaders modelled that what students have to say is important and worth listening to, and weighting the contributions of others when making decisions is a viable scientific practice. The SI leaders adopt a facilitative role situating students as scientists and spoke-persons in and for the class. Through this process, the students were encouraged to articulate their ideas, explain their reasoning and respect the ideas of their peers through these different forms of engagement.

The **relate** category of engagement theory is also evident in the notion of planning and preparation of tasks students engaged in prior to SI sessions, as well as in group activities during SI sessions. Data reveal that students needed to plan and prepare for SI to ensure that they acquired the most benefit from the sessions with respect to aspects of stoichiometry that posed problems in understanding:

> *…you feel like for the next SI I need to do this and I have to be prepared and you start preparing by doing other examples so you know what you don't understand.* [FG1]

Other opportunities students acquire with respect to planning and preparation are linked to group activity in which students are required to manage group dynamics in developing solutions to chemistry problems. Individual interviews reveal that all students in the group do not necessarily contribute to the problem solving activity:

> *I'll be honest everyone doesn't contribute I mean maybe they are just shy or not but we try and get everyone involved…* [ID4]

This form of disengagement with pedagogical content knowledge could be attributed to several factors, one of which is suggested in the data as being “shy”; this could be regarded as a lack of confidence or social skills development.

Social skills development is associated with the **relate** principle of engagement theory has been acknowledged by the students as a key principle of collaborative learning in developing confidence in learning engagement.

> *…we need to consult with people so we learn how to interact with people.* [FG2]

> *Group work boosts your confidence. It helps you to relate to people.* [FG2]

In this study, social skills were developed through group and peer discussions; students were asked to explain concepts on the chalkboard and contribute to class discussions on various stoichiometry concepts.

The above discussion demonstrates that the principle **relate** is demonstrated in several ways by the engineering students’ engagement, viz. through group and peer discussions, communicating team efforts, arriving at authentic consensus, taking up invitations to participate in class discussions, managing group dynamics and social skills development.

7.2.2 Create

The principle **create** can be used to frame the opportunities for engagement and learning created by the SI leader with respect to the different pedagogical activities, organisational skills and creation of safe non-judgmental learning space offered in the SI environment. The pedagogical activities include group discussion, paired problem solving, explanation of concepts on the chalkboard and the development of concept maps. The SI leaders create further invitations for engagement and learning by using questioning techniques such as probing, redirecting and prompting.

Kearsley & Shneiderman (1999) mention that since collaborative methods are novel for many students; they will require guidance in working together to achieve for example time management, leadership and consensus-building. The role of the facilitator becomes vital in supporting effective engagement and creation of the collaborative learning opportunities which are also evident in this study.

The SI leaders' role in creating opportunities for engagement was regarded as an important contributing factor in the way students engaged and contributed to chemistry learning. This was deemed an important aspect with respect to students' confidence and motivation to engage in the learning at SI sessions:

> *…the biggest contributing factor is our SI leader, she runs things in a certain organized way and there's no room for somebody to like mock at you or laugh at you if something's wrong and apart from that I guess that everybody who is attending SI is like similar to you in a way, whereby they also need help and so you don't feel so terrible about it…* [FG1]

The SI leaders' role in creating a safe non-judgmental learning engagement space seems to be valued by students. There is also a sense of equality with respect to students' learning needs in that students see their peers at SI on a similar ranking as themselves as they seek assistance with chemistry learning.

However, students were also found to create purposeful activities by engaging in collaborative learning activities, in developing an understanding of stoichiometry concepts, consulting their notes and textbooks as support for their discussions and engaging in critical review in establishing consensus. Students displayed a sense of control over their learning by creating opportunities to prepare for SI sessions, knowing which aspects of stoichiometry concepts posed problems to them, thus taking responsibility for their learning. Students further modelled SI leaders questioning techniques as a method for arriving at answers. SI seems to create opportunities for clarifying understanding of concepts which assists in answering problems:

> *We can just go home read the notes and if you don't understand anything come to SI, ask the questions and then once you gain the understanding, we can answer the questions and gain knowledge…* [FG2]

Students seem to take up these opportunities for engagement in developing an understanding of stoichiometry concepts and in a sense take responsibility for their learning.

In other instances, students have demonstrated a lack of responsibility for their learning with respect to their problem areas in stoichiometry. Many students admitted that they did not take questions to SI that were problem areas in their understanding, saying that "*it was too late*" [ID 1], meaning that the topic was already covered, or "*I think we did a similar example at SI*" [ID3]. It is apparent from these comments that some students merely relied on other students' questions or the SI leaders' activity worksheet for that session as a means of developing an understanding of chemistry concepts.

There are some instances in this study where students reveal a lack of control over their learning despite the opportunities created by the SI leader for engagement:

> *Group work not always good- because sometimes if you don't have a clue of what is happening, you end up asking and asking you feel a bit silly and like the silly person who doesn't know anything in that group* [FG 1]

Students here show a lack of understanding of the meta-cognitive skills required in learning and are more fixated on knowing the right answer rather than developing an understanding through discussion and support in the social learning spaces created.

It is evident from the discussion above that the principle 'create' in this study offers the engineering students several opportunities to engage by creating spaces for pedagogical activities, creating a safe non-judgemental learning environment and creating purposeful activities that allow students to take control of their learning.

7.2.3 Reflect

In this study, the principle of reflection was observed in terms of collaborative learning opportunities offered to students which inspired students to reflect on their understanding of stoichiometry concepts in group discussions. Feedback received during SI sessions offered students an opportunity to reflect on stoichiometry concepts in different ways viz. verifying the correct answer, consensus with respect to the correct answer as well as evaluation of answers and summarization of concepts.

It was also found that peer feedback was valued as a resource in student learning and deemed essential components in developing an understanding of chemistry concepts. It was evident that SI leader and peer feedback were regarded as scaffolds for the learning of chemistry concepts.

> *At SI there's a whole lot of other people there so they come in with different questions and different angles of thinking and for example if there is something that you feel that there's a set method in which to calculate, some other person might have a completely easier and different way to that, it saves you time….most probably their method is less time consuming.* [FG1]

Peer support and peer learning seems to give students exposure to a diversity of ideas on how to answer specific questions further to assisting students in developing a deeper understanding of concepts through the variation in methods to which they are exposed. Peer learning is also found to assist in developing an understanding of concepts through explanation and discussion in groups which results in students reflecting on their own understanding of concepts and assessing their understanding of certain concepts.

> *You may think you know something but in actual fact you don't understand it until you really go through it with other people and you get this whole new perspective and in that way you know that you have certain problem areas and it can help you in that way* [FG1]

Peer support was considered an important aspect of student learning through feedback in clarifying their understanding of concepts in a sense that "*other people can explain it to you in the way they see it and maybe you understand it better and that's why I really enjoy going to SI*" and this support was viewed as "*better that studying on your own*" [FG 2]

In attempting to determine if SI sessions encouraged students to take responsibility for their learning beyond peer and SI leader support in the social learning spaces created, it was established that students develop skills from peers and SI leaders which were modelled when engaging in individual learning tasks:

> *I do practise some of the things that we do in SI session at home alone so I did get more practice working on my own…* [ID 5]

The comments above reveal that student engagement with respect to the 'reflect' principle allowed the engineering students an opportunity to engage through reflection in several ways, viz. feedback, opportunities for questioning, support and modelling peers and SI leaders' behaviour.

The discussion with respect to **relate, create and reflect** in this study indicates that SI learning engagement complies and extends Kearsley & Shneiderman's (1999) model to include social learning spaces which facilitate student learning engagement in chemistry SI sessions.

7.3. Toward theorising a model of Social Learning Engagement in Chemistry SI

The model that follows Fig.7.1 is derived from the above discussion and illustrates how Kearsley & Shneiderman's (1999) engagement theory model can be extended to include the notion of social learning spaces which is the centre of most activities in the SI session. This model in its inducted form will be used to drive the emerging thesis which follows in the next chapter. This model depicts social learning engagement in chemistry SI sessions and suggests that there is another dimension to engagement theory and therefore extends Kearsley & Shneiderman's (1999) model to include social learning spaces.

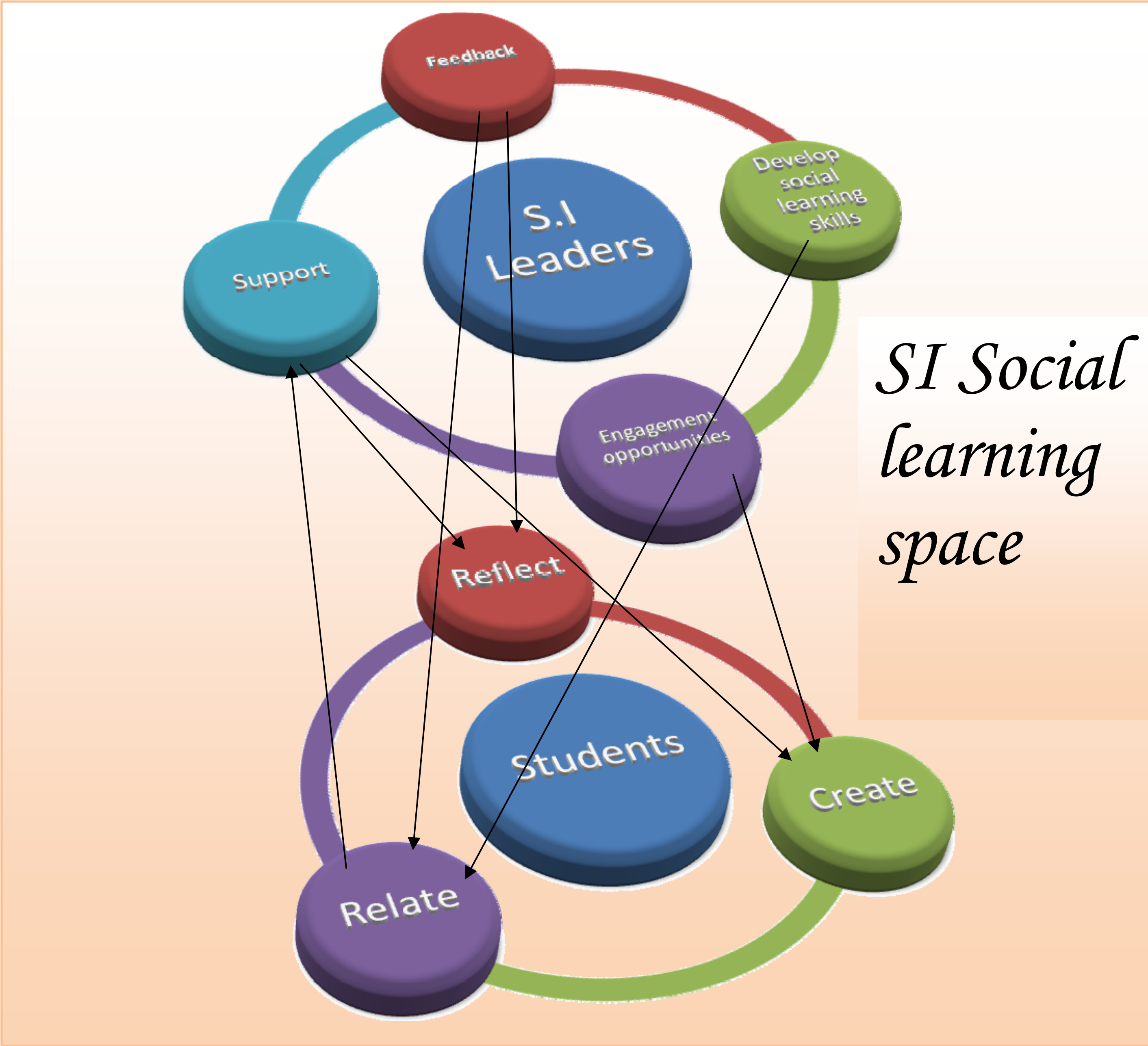

Figure: 7.1: Model of SI social learning engagement

(adapted from Rust, O' Donovan & Price (2005: 237)

The two parallel ongoing cycles, one for the SI leaders and the other for the students, should be seen as one dynamic system, each informing the other, with common understanding being shaped and constantly evolving within a community of practice (SI social learning spaces). This model reflects the active engagement and participation of students and SI leaders using a social constructivist approach to learning with the SI social learning spaces.

The model can be explained in terms of engagement theory where SI leaders' feedback and support in chemistry SI informs how students **relate** and **reflect** during the SI sessions. This is demonstrated in the ways students communicate and collaborate in group and peer discussions with feedback and support from the SI leaders. The **create** principle of student engagement in contrast can be used to frame the different pedagogical opportunities created by the SI leader for social learning engagement and the development of social learning skills such as time management, leadership qualities and critical thinking skills. This model is therefore significant in theorising a model of social learning engagement in chemistry SI.

7.4. Phenomenon of Social Learning Space

In order to move beyond the engineering students' engagement in the SI social learning spaces, the notion of **phenomenon of space** is used to theorise how students' get to know stoichiometry concepts in chemistry SI. Several theorists have considered the theory of space (Lefebvre, 1991; Soja, 1997 and Merleau-Ponty, 1945). Three important concepts with respect to the production of space is referred to by Lefebvre (1991: 38-39); these are spatial practice (perceived space), representations of space (conceived space) and representational space (lived space). Lefebvre (1991) argues that space is a social product. The space thus produced serves as a tool of thought and action and it is also a means of control, domination and power.

In this study, the issues of 'control, dominance and power' in terms of SI leaders being "in authority" as managers of classroom practices and "an authority" of science knowledge, have been discussed earlier reflecting that SI leaders assume a facilitative role. This prevents or counters one-sided arguments and dominance by certain students in knowledge construction of the leader as “an authority” of science knowledge but more of “in authority” as manager of creation and maintenance of the social learning spaces and socio-scientific norms with respect to developing authentic consensus, questioning techniques and discussions. In reflecting upon issues of control, domination and power with respect to students’ engagement in the social learning spaces in SI, data revealed that students’ epistemological beliefs influenced ways in which they engaged and got to know stoichiometry concepts. This notion of the influence of students epistemological beliefs is supported by Schommer-Aikins & Easter’s (2009: 117) study on ”ways of knowing and willingness to argue” which argued that the more students believed in simple knowledge and certain knowledge, the more likely they were to avoid argument (Nussbaum & Bendixen, 2003). I would extend this notion further to include a link between students’ epistemological beliefs and students’ engagement where data revealed that students who believed that knowledge is simple, certain and handed down by omniscient authority (Perry, 1968), were less willing to engage and contribute to stoichiometry discussions.

In order to move beyond engineering students’ engagements in the SI social learning spaces, the phenomenon of space is used to examine the creative function of language to get to know what students know about stoichiometry concepts.

To explain what phenomenological space represents in this study in a more practical way, I have borrowed the ideas of Diemers (2000), who writes about interpretative spaces and how these constitute virtual organisations and communities. These ideas are represented by Fig. 7.2 which follows:

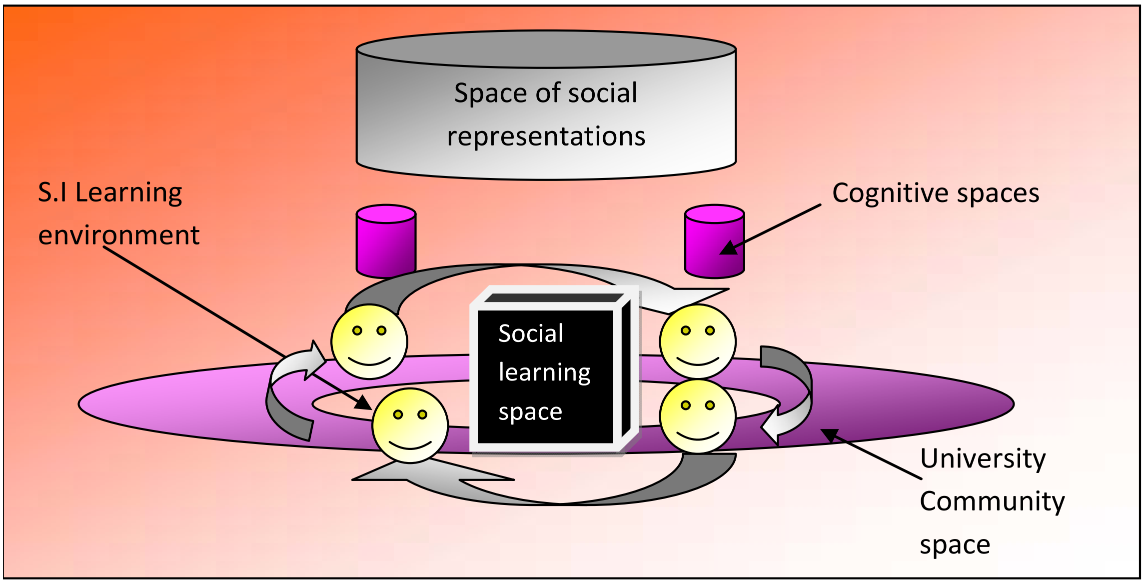

Figure 7.2: A spatial model of face-to-face communication between group members in SI social learning spaces adapted from (Diemers, 2000)

According to Diemers' definition of geographic space, the university community would represent one part of the foundation of all social interactions which engineering students have potential for and actually reach.

Phenomenological space is part of geographic space and would therefore represent the SI environment, being the immediate world in sight of the student that arranges itself spatially and temporally around the individual at the centre. According to Diemers (2000), external objects in phenomenological space are believed to appear to the individuals as phenomena, either through actual perception, attentive advertence or subsidiary awareness, and those perceived phenomena are structured and identified according to our individual set of meaning making structures, which reside in our cognitive space. In this instance, the external objects in the SI phenomenological space would represent the three imperatives that were derived from Engagement theory viz. relate, create and reflect, which emphasise all the social dimensions which are represented by these broad terms with respect to student engagement.

Cognitive space is constituted by the individual stock of knowledge and conceptual map. In this study, the stoichiometry pedagogical knowledge represents the cognitive space where meanings of phenomena are seen to be cognitively constructed by the perceiving subject.

The space of social representations as depicted by Figure 7.2, makes it possible that two individuals are able to interact in a social setting and attribute meaning to the utterance of the other. This space is created through the process of institutionalisation, when social practices are habitualised, shared and legitimated within a community, as is evident in the data from SI sessions. The SI leaders institutionalise practices of collaboration, questioning, feedback and consensus making in terms of socio-scientific norms which are practised during SI sessions. Diemers (2000), claims that the individuals in Figure 7.2 have a cognitive space, which is derived from the social space of representations and is constantly being compared and updated. In this study the cognitive space is constantly being compared and updated with respect to feedback, reflection, support, motivation and collaboration activities. The individuals share a geographic space and currently have their phenomenological spaces in congruency, which is typical of collaborative activities during SI.

The common interpretative space is the "specific set of signs, shared meanings, norms and values of the group of individuals interacting face-to-face, in co-presence with each other" Diemer (2000). It is created initially based on individual cognitive spaces, but undergoes a transformation during the process of focused interaction. When individuals have a similar cultural background, then there are fewer problems because it is believed that culture influences reasoning and knowledge constructs. Diemers suggests that their interaction will proceed well when group members meet each other often, resulting in improved interaction. This idea is reflected by the data in this study which claimed that when students know each other they feel more comfortable, and it is much easier to engage in the discussions and go up to the board to explain concepts.

At the end, emotions, trust and friendship may become part of the common interpretative space as suggested by the data of this study. This model clearly explains the engineering students' engagement during SI sessions, where students describe their experiences of collaborative learning during chemistry SI sessions in terms of developing shared meanings of concepts and through regular attendance to SI sessions, developing a sense of trust and the freedom to explain their understanding of stoichiometry concepts. This is revealed in the data by comments such as "*nobody is judging you because we are all sort of on the same level.*" [FG2].

Common interpretative space, cognitive space and the space of social representations are examples of the way people can be influenced and in this instance, in developing an understanding or knowing of stoichiometry concepts.

Oude Groeniger & van Veldhuizen (undated) assert that "space" is rich and complex. It is ordered with reference to human intentions and experience for we are immersed yet extended in space through our actions and perceptions. It is not obscure or abstract, but it is part of everyday experience. This study reveals that students get to engage with stoichiometry concepts in their experiences of the social learning spaces created by the SI leaders. Lefebvre's theory of space was used to illustrate the power dynamics whereas Diemers ideas of phenomenological space illustrated the relational dynamics of the SI learning environment. It would appear that Lefebvre's three categories of space (perceived, conceived and lived space) are linked to Diemers ideas of phenomenological space (geographic space, space of social representation and common interpretative space) so as to produce a Venn-diagram effect. However, the power dimensions in the SI learning space was not explicitly explored as these ideas only emerged late in the study. This offers a possibility for further research.

7.5 Conclusion

This chapter argues that students' engagement in SI sessions is determined by how they **relate, create** and **reflect** with respect to engagement theory and that they get to know what they know about stoichiometry through the phenomenon of space in the social learning spaces that are created during chemistry SI sessions. Ideas around engagement theory and the phenomenology of space were borrowed to drive the thesis which follows. How students get to know what they know with respect to stoichiometry is interrogated next and the insights that emerge out of that knowing and knowledge will be discussed. Having established a model of student learning engagement in chemistry SI, the different ways students get to know and understand stoichiometry concepts in these social learning spaces will be theorised in the next chapter.

CHAPTER EIGHT

THESIS: PHENOMENON OF LEARNING ENGAGEMENT HOW DO STUDENTS GET TO KNOW WHAT THEY KNOW ABOUT STOICHIOMETRY?

8.1 Introduction

This chapter is divided into five sections. The first part summarises the data analysis chapter in relation to the findings of the study. The second part theorises the nature of knowing in Science in relation to the findings. In third, fourth and fifth parts implications for learning engagement are considered with stoichiometry concepts, Supplemental Instruction and higher education respectively. Finally, I reflect upon the study, making some concluding remarks.

8.2 Students' Learning Engagement

A social constructivist theoretical framework was utilised to understand students' engagement in the chemistry SI sessions, as SI is based on social constructivism principles. Although a social constructivism theoretical framing was adopted in the data analysis chapters, in many ways this thesis chapter was almost at risk, given that chemistry knowledge is regarded as fixed, final and formulaic in the way it is taught. It therefore sounds almost antithetical to be using a theory of social constructivism in theorising about the results of my study. The data however confirms that students' learning engagement can actually subscribe to the principles of social constructivism in different ways in the SI social learning spaces.

Aksela (2005), however, claims that science has a social nature. Much of modern-day science is conducted by groups of scientists rather than individuals, i.e. using distributed reasoning (Dunbar, 1995; 1997; Thagard, 1997). Scientists externalise much of their thinking through interactions with other scientists in the laboratory. The scientist is seen as part of a social group that has a very important role in the creative process (Dunbar, 1999a). This implies that all science learning, be it in the laboratory or classroom, should follow a social learning nature. These claims are significant in light of the findings of this study which emphasis the social learning engagement experiences of engineering students in developing their understanding of stoichiometry concepts.

As discussed in Chapter Seven, section 7.2, Kearsley & Shneiderman's (1999) model on engagement theory was used to theorise the results of this study. Engagement theory has its emphasis on meaningful learning which is consistent with constructivist approaches, collaboration among peers and a community of learners.

8.3 The nature of knowing in Science in particular stoichiometry in chemistry

The findings from this study have implications for what it means to know pedagogical content knowledge in the context of higher education. According to Amin (2008), dictionaries and other text separate the meanings of the term knowing from knowledge, but in practice the two are used synonymously even by theorists (Cunliffe, 2005; Fenstermacher, 1994; Kupers, 2005; Tirri, Husu & Kansanen, 1999), with their meanings blurred and knowing in particular, often interpolating knowledge. The terms **knowing** and **knowledge** were brought together in the study of teachers knowing about students' to explore how they differ and are similar, is necessitated by the everyday interchangeable use of these terms, used synonymously, regarded as insignificantly different or when they signify different things. This understanding of knowing and knowledge is significant in my study in order to understand when engineering students' knowing of stoichiometry concepts translates into knowledge or understanding.

In my study, students' often remarked "*I know now how to answer that question*" implying that the discussions and explanations offered during SI sessions assisted them in understanding the stoichiometry concept being discussed. Amin (2008) concludes that knowledge can be interpreted as precise and knowing as tentative; in other words, knowing is pre-knowledge or knowledge is post-knowing. Language therefore plays a significant role in understanding students' engagement with stoichiometry concepts in chemistry SI.

Crawford, Kelly and Brown (1999) have indicated that studies of student learning in science contexts are increasingly focused on discourse processes and language. Language is believed to play a prominent role in many scientific practices for both practitioners and students in making observations of phenomena, articulating relevant interpretations, making decisions about collective actions, constructing arguments, supporting particular positions and questioning experimental results. The use of scientific language is evident in the chemistry SI sessions in the ways students and SI leaders construct meanings of stoichiometry concepts in the social learning spaces. The rhetorical and discursive aspects of teaching and learning scientific concepts, practices and ways of being a group member have led educators to define science as discourse (Roth, McGinn & Bowen, 1996) to compare the learning of science to the learning of a new language with particular semantic, syntactic, and ideological implications (Lemke, 1990), and to consider the ways that language use is related to group affiliation (Moje, 1995, 1997).

The ways discourse processes used by engineering students and their SI leaders in this study contributed to the construction of classroom norms and interactional contexts, and ways of doing and talking science were of central concern for this study in establishing how students engaged in chemistry SI sessions. To examine how this community of students constructed ways of investigating and knowing in chemistry SI, socio-cultural theories of learning (Vygotsky, Bandura and Wenger) and engagement theory (Kearsley & Shneiderman) were drawn upon and applied to an analysis of classroom discourse. Through this analysis of the SI leaders' and students' talk and actions, the discursive processes used by students to investigate stoichiometry concepts in chemistry have been described. An analysis of the concerted activities of the SI leaders and students provided the basis for a discussion of how opportunities for learning (Tuyay, Jennings, & Dixon, 1995), ways of knowing and practising science are constructed discursively among members of a chemistry SI community.

In this study, the SI leaders posed a range of different types of questions to students in an attempt to provide opportunities for learning engagement within the chemistry SI social learning spaces. It is also interesting to note how the SI leader is an authority on the social scientific norms that drive the discussions and engagement with stoichiometry concepts, but is less of an authority on knowledge that is constructed together in theses spaces. The SI leader in these instances serves the role of facilitator of knowledge rather than an authority on knowledge and in a sense modelled for students the grammatical features of scientific discourse. Moje's (1995, 1997) study on teacher's talk about science coheres with the findings of this study with respect to the SI leader's role as facilitator, where she identified how uses of particular discourse processes (e.g., demarcating science from other disciplines) positioned science and science teachers as the authority and suggested that teachers serve as resources of questions and guidance for student learning, rather than definitive sources of knowledge. Issues of the status of authority in classroom discourse were also examined by Russell (1983) through analysis of argumentation structures of science teaching. He considered how teachers are "in authority" in their role of classroom manager, and "an authority" of science for their students. Russell argued that teachers can be scientific authorities when they provide evidential arguments for the claims they seek to establish, thus modelling for students the grammatical features of scientific discourse. Expanding beyond the uses of argument, Carlsen's (1991, 1992, 1993) sociolinguistic studies of the syntactic, semantic, and pragmatic features of classroom discourse demonstrated that teachers' discourse processes do more than teach science concepts and methods; they teach students about science as a process. It is therefore interesting to note that the SI leaders' classroom discourse plays a fundamental role in influencing student engagement in SI sessions.

This study reveals that SI sessions follow a ritual of students presenting their ideas for solving stoichiometry problems and reflection on their peers' ideas, through whole class discussions and defence of their own reasoning and substantiation of their claims. The SI leader or 'more knowledgeable other' had an important role to play in assisting students develop the necessary skills and strategies to acquire the discourse and deep understanding of chemistry concepts through reflection of their understandings. This study also emphasises that those students who did not engage in these SI activities were less likely to improve their performance in tests and examinations, which is evident in the responses from individual interviews and examination results which revealed a 90% pass rate for the non-Chemical engineering students attending SI. Two students who were regarded as regular attendees to SI sessions obtained less than 50% in their chemistry examination.

In a series of studies on language minority students learning science, Warren, Rosebery, and Conant (Warren & Rosebery, 1995; Warren, Rosebery, & Conant, 1994) worked with teachers to create conditions of authentic practice in classrooms. The teaching strategy in these studies emphasised questioning, theory building, and the development of scientific arguments. In one example, a teacher created conditions for students to present their ideas to their peers in the class (Warren & Rosebery, 1995). Through a sequence of challenges and rebuttals, a student investigator struggled to prove persuasively that his assertions were warranted in the face of questions from his peers. The class discussions about the student investigator's experiment provided opportunities for the whole class to learn about many important aspects of scientific discourse: use of data, argumentation strategies, the importance of norms of the local community, and the relationship of facts to arguments. Warren and Rosebery argued that the teacher played an important role by helping students develop the skills and strategies necessary to acquire this discourse of science.

Engineering students engagement in chemistry SI can be described as inquiry processes with respect to problem solving and social practices utilising the knowledge and expertise of others, living with uncertainty, articulating ideas in public forums, using evidence, reaching consensus, and making group decisions which can be regarded as learning of chemistry as a *social entrepreneurship*[21]. This involved engineering students getting to know stoichiometry concepts through taking risks and initiatives in the SI social learning spaces. The educational opportunities afforded under these conditions, offered students ways of seeing science as constructed through conventionalised social practices.

[21] Social entrepreneurship of learning was a term coined by Prof. Reshma Sookrajh in her deliberation of my thesis (A risk and initiative-taking learning endeavor utilizing the knowledge and expertise of others in an attempt to capitalise on chemistry knowledge).

In comparison, in Crawford, Kelly & Brown's (1999) study of how teachers, students, and scientists constructed ways of investigating and knowing in science, it was found that learning of science was constructed as a social accomplishment. The students in this study were offered opportunities to use their knowledge in inquiry processes (posing questions, observing, offering interpretations) and associated social practices (group norms for speaking and listening, particular ways of formulating an explanation) to "talk science" (Lemke, 1990:1).

It is evident from the above discussion that students get to know science or in particular stoichiometry through teachers' or SI leaders' discourse processes, which do more than teach science concepts and methods: they teach students about science as a process. Students also get to know chemistry through teachers or SI leaders modelling for students the grammatical features of scientific discourse by providing evidential arguments for the claims they seek to establish. Opportunities for the whole class to learn about many important aspects of scientific discourse are evident: use of data, argumentation strategies, the importance of norms of the local community, and the relationship of facts to arguments.

8.4 Implications for learning engagement with stoichiometry concepts

An important element of the study was to explore the ways in which the SI leaders were able to provide support for student engagement in development of a deep understanding and higher-order thinking skills in stoichiometry. To explore this aspect of the learning further, students were asked to describe the ways in which they felt the SI learning environment assisted with their learning. A number of patterns emerged in the responses that were given. In particular, support for learning stoichiometry was perceived to stem from the ways in which SI leaders scaffold the learning, as well as student- focused activities and concept development.

8.4.1 Scaffolds for learning

Many students described the ways in which SI leaders were seen to provide a strong supporting structure for their learning process. The feedback suggested that:

- ❖ Exposure to different activities by SI leaders e.g. questioning techniques, explaining answers and peer learning, encouraged the students to engage with stoichiometry concepts in ways they normally might not have on their own.
- ❖ Motivation and encouragement to pursue challenging tasks by SI leaders was seen to inspire learning.
- ❖ Constant feedback provided by the SI leaders with respect to problem solving activities was viewed as strong support for learning progress.

8.4.2 Student focused learning

Students commented that student focused learning which involved peer teaching and learning encouraged them to:

- ❖ Develop thinking, reasoning and social skills which enabled them to engage with the problem solving activities more effectively.
- ❖ Develop confidence with respect to making appropriate choices in terms of stoichiometry concepts.
- ❖ Explore, question and research other alternates as a fundamental component of their learning.

8.4.3 Conceptual development

SI sessions required students to bring their problems and difficulties to the session. SI sessions are therefore based on a problem solving context which requires more active engagement on the part of the students in learning process. Many students recognised the benefits of the problem solving process in deriving meaning from the information and content they worked with and their responses indicated that problem solving aided their learning by:

- Being exposed to problem situations which put theory into practice.
- Making textbook material and class notes more user friendly.
- Formulating links between prior knowledge and new concepts in stoichiometry.

Data suggest a sense of knowing but do students really get to know about stoichiometry in the way that they should acquire a deep understanding of concepts? This question is significant in that both nationally and internationally students and teachers regard stoichiometry as being difficult and un-motivating (Fach, de Boer & Parchmann, 2007).

There has been a vast amount of research that has covered stoichiometry problems in recent years, as indicated in the literature review (Chapter Two, section 2.8) of this study. This is so because on the one hand, students have to switch from thinking about concrete aspects of matter to more abstract thinking concerning aspects of particles (BouJaoude and Barakat, 2003). On the other hand, many authors agree that the concept is very difficult for students to grasp and therefore discouraging (Schmidt and Jigneus, 2003). Findings from this study show that SI creates opportunities for learning engagement with stoichiometry concepts that differ from lectures in many ways, by:

- Offering more opportunities for practice and reflection.
- Access to a variety of questions.
- Access to support and immediate feedback.
- Opportunities for collaboration.
- Taking responsibility for learning.
- Motivation to learn.

These opportunities for engagement offered in SI sessions cohere with Crawford, Kelly & Brown's (1999) study of how teachers, students, and scientists constructed ways of investigating and knowing in science. This implies that SI offers opportunities for engagement and knowing of stoichiometry which goes beyond the use of algorithmic strategies of solving stoichiometry problems and have the potential to alleviate many of the students' misconceptions in learning stoichiometry, as reflected by Mitchell and Gunstone (1984); Schmidt, (1990); Huddle & Pillay, (1996), and BouJaoude & Barakat, (2000), as indicated in Chapter Three, section 3.8. This reveals that SI therefore has the potential to develop students abstract reasoning skills through reflection, questioning and feedback.

Ways of acting, reasoning and arguing that are normative in a SI classroom community thus frame a students' reasoning as an act of participation (Cobb et al., 2001). In SI the dialogue is not made up of questions and answers but rather aims at rephrasing and redirecting the original questions. This allows the students to see the phenomenon from different angles and to develop concepts and achieve a more profound understanding of a phenomenon (Mannikko-Barbutiu and Sjogrund, 2004).

The findings support the argument that students' active engagement in scientific processes of problem solving within the social spaces encouraged the articulation of stoichiometry concepts, and allowed students to warrant their claims and respect the ideas of their peers in constructing an understanding of stoichiometry concepts. Data reflect that students get to know stoichiometry through the use of scientific discourse, feedback, reflection, rephrasing and redirecting questions and support of their claims through explanation and reaching consensus. Engagement within chemistry SI learning spaces appear very rich and engaging but in some instances, translation of knowledge into an actionable idea is limited, as evident in the perusal of test and examination scripts of certain students attending SI. There could be several reasons for this miss- match in students' knowing, one of which could be attributed to the fact that time constraints do not play a significant role in SI sessions whereas tests and examinations are more structured and are time-dependent.

8.5 Implications for higher education

Improving student success and throughput rates are key challenges facing South African higher education. International research shows that a focus on student engagement can help to enhance student learning and other desired outcomes as well as the efficiency and effectiveness of higher education systems (Strydom, Kuh &

Mentz, 2009). The data sets provided in this study, clearly indicate the need for more active and collaborative ways of learning. This need stems from both a student point of view and a national requirement point of view as stated by Strydom et.al(2009). From the student point of view, there seems to be a "cry" or urgent desire by students wanting to spend more time with a subject authority or more 'knowledgeable other' as referred to by Vygotskian principles, in a less formal setting, to overcome their loneliness of not knowing. Data has revealed that active learning in chemistry SI not only promoted enhanced retention of information but also permitted students to explore stoichiometry concepts in a manner which best suited their respective learning styles.

This study therefore has implications for national higher education and leadership of higher educational institutions to fulfil their responsibilities by taking up the challenge of providing appropriate, highly interactive social learning spaces that encourage collaborative learning, following SI principles, in non-threatening environments to meet the expanding needs for more successful graduates. Encouraging learning through engagement methods within a supportive campus environment will lead to a more enriching educational experience, as proposed by Strydom et.al(2009).

In the longer term, this study will also have implications for improving conventional teaching and learning practices at higher education level and will thus impact staff development in the various subject schools. To sustain improved students' levels of active engagement, curriculum reform may be considered. Lastly, this study will also influence enriching new institutional research in teaching and learning, with the focus being throughput and success rates.

8.6 Implications for Chemistry Supplemental Instruction in higher education

The SI leaders' role in creating and maintaining effective social learning spaces for engagement with chemistry concepts is highlighted by this study as being of utmost importance in sustaining collaboration, engagement and a deep understanding of concepts. The findings of this study seem to indicate firstly that SI leaders face several challenges in their attempts to engage students with chemistry concepts or more specifically with stoichiometry concepts, that of developing a culture of responsibility for learning with students maintaining their facilitative roles ensuring all students engage with content material. The findings further reveal that SI leaders need to constantly reflect on these challenges in order to effectively engage and support students during SI sessions.

Secondly, the use of a design research methodology in this study allowed for cycles of innovations and revision (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003). This iterative process of data collection and analysis allowed for support of SI leaders with respect to reflections on sessions and constant revision of facilitation styles and support material.

This study reveals the implications for training, monitoring and support of SI leaders by SI supervisors as crucial to the success of SI student engagement. It is evident that the success of the SI programme is dependent on effective training by SI supervisors and constant monitoring and support of SI leaders by SI supervisors and other SI leaders.

Data reveal that time constraints are major stumbling blocks with respect to effective collaboration and engagement in SI sessions. Students have suggested that double period sessions which span over one and half hours are more effective than 45 minute sessions. A challenge would be to organise more than one double period session per week considering the engineering students heavy workload per week.

Lastly, this study fills the gap of limited number of qualitative studies in SI as well as students' engagement in SI in South Africa and abroad. It provides insights into engineering students' engagement with chemistry concepts and moves beyond engagement to students' knowing of stoichiometry in the SI social learning spaces, a term which is coined as *social entrepreneurship* of learning.

8.7 Conclusion

This study has explored how engineering students engage in chemistry SI in developing an understanding of stoichiometry concepts. A design research methodology was used to estimate the effectiveness of the SI intervention in engaging students with stoichiometry concepts. This study makes use of an interpretative paradigm to analyse first year engineering students' engagement in chemistry SI. It has been revealed that the SI learning environment influences student engagement through pedagogical and social means, whereas engineering students are found to engage experientially and strategically through social learning engagement. Engagement theory theorises that the engineering students engage according to the principles **relate, create and reflect** in the social learning spaces. The phenomenon of learning is used to extend the thesis beyond student engagement to understanding how the engineering students get to know stoichiometry in social learning spaces which can be regarded a social entrepreneurship of learning.

The findings from this study suggest that chemistry SI has the potential to increase the quality of chemistry teaching and learning provided that students develop a culture of taking responsibility for their learning, and through increasing the number of students attending SI sessions. Further, SI leaders' needs to be effectively trained, supported and mentored. Faculty also needs to play a more substantive role in promoting and maintaining the interests in chemistry SI.

This study raises the need for more collaborative teaching and learning styles in chemistry which engage students with chemistry content and move beyond a sense of knowing to understanding. A need for greater support by disciplinary specialists with respect to encouraging student attendance at SI sessions, as well as engaging in reflective discussions with respect to difficulties students experience at SI and improving practice in teaching and learning in chemistry SI, are deemed essential for the effectiveness of SI.

The various discussions and conclusions below, will illustrate a growing contention by numerous researchers that the declining throughput rates at South African universities need urgent attention if we are to achieve the promotion of social equality and individual growth (Blackie, 2010). There are strong arguments on both sides of the debate to modify science curriculum to suit an under-prepared first year student situation. However, all stakeholders involved agree that the throughput rate must improve. Thus far, attempts at addressing the impasse, tend toward additional support programmes to counter the prevailing imbalances. This study, supported by other South African contextualised studies, using globally established theories and methodologies, focuses on improving the effectiveness of chemistry teaching and learning through the SI intervention.

Social Learning Spaces

The phenomenon of learning, but more specifically, the phenomenon of social learning engagement has emerged in this study as a significant factor for student engagement in chemistry SI. In examining the research data compiled from the various interviews and observations of SI sessions at UKZN, the concept of social learning space reveals itself as the most crucial element influencing student engagement. While the element of social learning spaces is the key focus of this study, the concept of social learning spaces has pronounced itself in other earlier studies which however have had different key focuses.

According to Mann (2001), we are responsible for providing an environment which is engaging, rather than alienating and in which the majority of students can develop intellectually and personally, As proposed by Strydom et al (2009), encouraging learning through engagement methods, (including social learning spaces), within a supportive campus environment will lead to a more enriching learning experience. Crawford, Kelly and Brown (1999) found that the learning of science was constructed as a social accomplishment, which also comprises social learning spaces. Aksela (2005), claims that science has a social nature. Different kinds of communications, (written and oral), are central within the community of scientists. Scientists externalise much of their thinking through interactions with other scientists. This implies that all science learning should follow a social learning nature, within a space that allows for appropriate exchanges of discussions that support social learning. This appropriate social space allows for reflection and collaboration that improves understanding of science concepts.

Reflection

As discussed throughout this study, an important activity undertaken in the conducive social learning space is reflection. Reflections in the chemistry SI sessions allow students opportunities to challenge their own understanding of concepts and provided students are willing to adjust their understandings, they will be developing their meta-cognitive learning skills. According to Davidowitz and Rollnick (2001), and Hennessey (2003), a meta-cognitive approach may induce a deeper level of understanding concepts. Chapter Three, the theoretical framing of this study, is concluded by showing that the student activity of reflection is an important tool in the development of their meta-cognitive skills to achieve conceptual change. This manner of achieving conceptual change fits into the SI methodology which is based on a social constructivist framework. A critical activity of reflection is students externalising their conceptual understandings of chemistry/stoichiometry, as undertaken in the chemistry SI sessions at UKZN.

Assessing Conceptual Understanding

One of the methods as described by Dewey (1963), for "testing" conceptual understanding is communicating one's findings. It is only when one tries to articulate or formally express one's thinking, that one discovers the holes in one's logic. Many a university lecturer has commented on the experience that they only truly began to understand aspects of their subject when they began to teach it. In trying to communicate thoughts and ideas one is forced to probe them at greater depth. In so doing, often connections are made around which meaning begins to crystallise. Creating opportunities in social learning spaces is a cornerstone of the chemistry SI methodology at UKZN. As revealed in the data collected, students commented that they understood more when reflecting upon a concept while discussing either in pairs, groups or when called to explain to the class on the chalkboard.

Popper and Dewey, cited in Blackie (2010), provide us with a powerful imperative to create space for scholarly reflection and critique. We need to hold this social learning space for our chemistry students, but perhaps the only way we will truly begin to see the value of this, is if we dare to reflect upon and critique the curriculum itself on a regular basis.

The findings from this study are suggesting that higher education needs to create sustainable SI learning spaces for the collaboration of students with chemistry concepts which will facilitate the shift of SI learning principles into the mainstream curriculum, and where through collaboration and interactive learning engagement students can reshape the ways they develop meta-cognitive learning skills that promote life-long learning which is in line with the goals of Project Sustain and ultimately an increase in the throughput of engineering students which adheres to the goals of the TIES project.

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LIST OF APPENDICES

Appendix 1

Chemistry Pass Rates for Engineering Students

Sum of Field 1	Year			
Module	2005	2006	2007	2008
CHEM161	94%	99%	100%	100%
CHEM171	86%	97%	86%	97%
CHEM181	70%	80%	90%	86%
CHEM191	80%	95%	71%	61%

Sum of Any Pass?		**Year**		
Module	**Final Mark 2**	**2005**	**2006**	**2007**
CHEM 161	50-59	39	14	7
	60-69	37	34	11
	70-79	36	19	27
	80-89	13	10	20
	90-100	2	2	6
CHEM 161 Total		127	79	71
CHEM 171	50-59	71	13	19
	60-69	39	29	25
	70-79	14	20	9
	80-89	7	13	6
	90-100	1		1
CHEM 171 Total		132	75	60
CHEM 181	50-59	198	174	153
	60-69	111	100	95
	70-79	36	33	24
	80-89	2	11	4
	90-100		5	2
CHEM 181 Total		347	323	278
CHEM 191	50-59	158	175	128
	60-69	103	92	53
	70-79	63	19	11
	80-89	19	8	3
	90-100	2	1	1
CHEM 191 Total		345	295	196

The Phenomenon of Learning

Appendix 2

SI Leaders Reflective Journal

Date: 09/08/09

1. What teaching and learning strategies worked for you during the SI session?

Group Work

Visual Aids

2. How do you know (or what were the indications) that these strategies enabled students to develop a deep understanding of the concepts being discussed?

During group discussions, I was able to observe that students', who were previously unsure of certain questions or answers, seemed to understand after discussing with their peers. I found that some students were unable to understand certain questions OR concepts until something was written or drawn on the board.

Seeing a relevant diagram or equation appeared to trigger their memory and encourage better understanding.

3. What type of questions were the students asking? (procedural, administrative or developmental). Explain

Most questions asked students appeared to be procedural and administrative.

Many students were more keen on getting the final answer rather than understanding exactly how to get to the answer themselves.

The Phenomenon of Learning

4. Which techniques employed by you during the session did not achieve deep understanding and higher order thinking?(i.e students were unable to critise or evaluate concepts)

I tried to use visual techniques to help the students draw up the periodic table - Some students tried genuinely, while others just did not bother because they thought that they did not know it. Students could not adequately recall the periodic table and even though they have all used the periodic table previously, they were unable to draw on previous experiences or knowledge.

5. Where you able to salvage the situation? If yes, how?

Yes, By promoting and probing them at certain times, they were finally able to draw a rough periodic table of the first 20 elements.

6. What would you do differently in the next session?

I find that I sometimes let them ponder on things a little too long. Next time I will probably intervene, make suggestions or prompt students sooner and not allow them to get to the point where they feel that the situation is hopeless.

Appendix 3

Students understanding of learning

Social engagement

Responsibility for learning

Focus Group Interviews – FG 1

1. What are your experiences of the SI sessions? What motivates you to attend chemistry SI?

1. **Mbonga-** It was good!
2.**Nokuthula-**. I think it is the way that they give us questions and it's the questions are
3.much tougher than our tuts – so when we get to a test we are not like surprised when
4.we find something new.

5.**Noma** - I'd say I like the fact that they pay special attention to every persons needs and
6.you are given a chance to explain something in your own words therefore you know
7.whether you've finally got something or the rhythm of something or not.

8.**Nelli** - Ja, like the fact that it actually improves your understanding like for instances
9.we getting new notes and stuff which is an added bonus to us to what we have in class.

10.**Praveena-** I feel that one of the good experiences are that you get to work in groups
11.and with different people which really clarifies your understanding of chemistry
12.concepts because people might really have different views, methods or ways of
13.working out stuff and ..so in that way I think it clarifies chemistry concepts which I think is a good thing

14.**Noma-** They are good because as we can see where you are really lacking and if
15.maybe you thought that you knew a particular part and you find a difficultquestion
16.then you can see that no, I didn't really understand then you can review and refresh
17.your memory at the same time on that concept.

Appendix 4

Interview with Nivashan

RESEARCHER: Why do you think that when you teach somebody something you getting a better understanding of concepts

1.N: I think its because often when you…….often when you….think you know 2.something you realise that unless somebody approaches you and asks you a question 3.about the topic which you think you know about and teach then along the way then you 4.also realise there's some also loop holes in places that you wouldn't know and that 5.people ask that question and you think to your self but I didn't know that……
6.So you…you further your understanding about the subjects by going back and trying to 7.remember what you did

RESEARCHER: Do you find that this type of learning happens a lot in SI?

8.N: Yes it does happen a lot because sometimes you think you know a subject but when 9.you get to SI and somebody asks a question and then you'll be like….I thought I knew 10.all about the subject but when that person asked the question you realise you totally 11.stumped when they asked the question so that helps a lot

RESEARCHER: Just to clarify, you mentioned in the focus group interview, "She gives us direction and through this direction we are able to understand stuff" what type of direction does the SI leader give you.

12.N: Well it's hard to explain…well she gives us an indication with what to start with….
13.and then from there what to start but she doesn't give detailed of what to do next, she 14.makes us think about it and then discuss it amongst each other and if we discuss 15.amongst each other and if we……if we…..if we still like unsure we'll ask her about it 16.but generally by doing that we are able to work together and then we are able to 17.finally find an answer and we find…if by any chance the answer is wrong then we go 18.back and then she corrects where we made a mistake by asking one of us to write the 19.answer on the board to explain the answer and then generally even if the answer is 20.wrong or right, it doesn't matter as long as you know in which direction you going and

she provides that direction … or by giving you a hint. She also asks what do you understand by the question? This generally makes you think about what information is give and what is required.

Appendix 5

Transcript of Video data

Lesson 1 (24 /07/2009)

Module: Group 2

Invitations for social spaces

Consensus

Feedback

SI 1: So first step for combustion analysis problems is 1- Find the number of moles. Based on what you have you can find the number of moles of carbon and hydrogen. Then if there's oxygen present……..present then – what do we have to do to find the mass of oxygen?

Joe: Minus the carbon.

SI 1: The next step you find the mass of those two things, OK. And you know that this is coming from CO_2 and this is coming from H_2O. Once you've got the mass of C and H, we can find the mass of – an oxygen containing compound – next we can Find the mass of O. After we have done this mass, we can find the number of moles. So how do we actually find the mass of O from carbon and hydrogen? Anyone?

A2: Is it not the balance of the, what you're given – I mean you've got the mass of carbon and hydrogen that is remaining.

A1: You take the mass of the sample minus – you subtract the sum of the mass of carbon and hydrogen.

SI 1: You all agree with that? Can you repeat what you just said there?

S: You subtract the sum of the mass of the carbon and hydrogen from the mass of the sample.

SI 1: Just to summarise. You'll all know the number of moles of each one. I'll just call it "x", "y" and "z", and then you'll just have to find the simplest – the empirical formula, the ratio based on the numbers.