Exploring the use of supplemental instruction: Supporting deep understanding and higher-order thinking in Chemistry

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Abstract
Many under-prepared university students do not know how to study (Martin and Arendale 1993) 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 article draws from selected findings from a PhD study currently being undertaken at a university in KwaZulu-Natal. This article explores the use of Supplemental Instruction (SI) in supporting deep understanding and higher-order thinking skills (HOTS) in stoichiometry in first year chemistry for engineers. The special focus of this article is to investigate whether the quality of teaching and learning in chemistry education is improved through SI and SI leader intervention. The central question guiding this article is: How does an interactive teaching and learning intervention programme (SI) facilitated by SI leaders potentially engage first year engineering students in deep understanding and HOTS in Chemistry?

Since this article focuses on change or growth in natural settings, within stoichiometry in chemistry classrooms, it allowed for video-recordings, observations of SI sessions and focus group interviews which have been used in this study.

Data analysis revealed that students preferred the more interactive engagement of SI sessions and discussion around chemistry concepts. Students found that having to explain concepts in their own words and being exposed to other students methods of answering questions greatly improved their understanding of stoichiometry. It was also found that SI leaders encouraged HOTS by asking higher-order questions, engaging in activities that required higher-order thinking as well as encouraged students to reflect on their thinking. It is therefore argued that teaching and learning strategies employed during the SI intervention session have the potential to promote deep understanding and higher-order thinking.
INTRODUCTION
First year students in high risk courses often experience a number of difficulties that can limit their potential to succeed and achieve (McInnis et al. 2000). The faculty of Science and Agriculture at a selected 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. Thus Supplemental Instruction has been introduced as a support programme for the first year engineering students. This article proposes to understand SI leader engagement at Supplemental Instruction (SI) sessions in developing deep understanding and higher-order thinking skills (HOTS) in chemistry for first year engineering students. It is assumed that the primary focus of SI sessions is aiding student assimilation and understanding of course content by thinking, reasoning, analyzing and problem-solving (Phelps and Evans 2006). Martin and Arendale (1993) have stated that SI leaders can assist students engage in thinking behaviour which facilitates connections between notes, textbooks and problem-solving. This is done in different ways which include students in SI sessions working collaboratively to understand the course concepts, brainstorming ideas, and engaging in discussions of how the concepts relate to each other. These activities facilitate their greater conceptual understanding, and their success on problem-solving tasks and examinations increases substantially (McGuire 2006). This article begins with a discussion of selected literature in which concepts are clarified and learning theories that encourage the use of HOTS and deep level thinking are explored. The methodology used in this study is then explored and the findings captured. The results from the observation schedule, video recordings and focus group interviews are then analysed to determine the ways in which SI leaders were able to engage students in development of deep understanding and higher order thinking in stoichiometry.

BACKGROUND
A review of literature related to the concept of deep understanding, higher-order thinking and Supplemental Instruction with respect to stoichiometry in Chemistry is examined within local and international studies. The main aim of this study is to improve the quality of chemistry education at the college and it is therefore essential to understand the elements that contribute to quality teaching and learning. It has been established that deep understanding is synonymous with quality teaching and learning (Biggs 2003) and Supplemental Instruction is believed to promote higher order thinking skills (University 2008).

SUPPLEMENTAL INSTRUCTION AND ITS CONTRIBUTION TO THE RESEARCH ENVIRONMENT
Research has indicated that studies supporting the effectiveness of SI cover a cross section of undergraduate courses, including sociology, chemistry, economics,
engineering, history, mathematics, law and accounting (Carson and Plaskitt 1994; Collis and Ronaldson 1995; Etter et al. 2000; Kotze 1994; Smit 1996). However, some studies have not found SI to be effective in improving student performance, for example Warren and Tonsetic (1998). They detected no significant differences in SI and non-SI student grades for multiple sections of political science and calculus courses.

Collaborative learning strategies were used in SI sessions as a means of creating a more active learning environment for student participants. Supplemental Instruction characterises the following as attributes of active learning and as part of an SI session:

- Less emphasis on transmission of information and more on developing students’ skills.
- Students are involved in higher order thinking analysis, synthesis and evaluation.
- Students are engaged in activities (reading, discussion, writing).
- Greater emphasis is placed on students’ exploration of their own attitudes and values.
- Students work interdependently and hold each other accountable. Students process their group effectiveness.

The SI sessions were designed to engage students in peer discussions with an emphasis on interactive teaching and learning strategies which attempted to promote deep understand and higher order thinking in the first year Engineering students.

**Higher-order thinking**

In this study higher-order thinking skills (HOTS) are regarded as cognitive processes (skills) that can be categorized as remember, understand, apply, analyse, evaluate and create, which is a revised version of Bloom’s Taxonomy. The last four categories are usually designated as higher-order thinking skills. According to Resnick (1987), higher-order thinking is non-algorithmic, complex, often yields multiple solutions, involves nuanced judgement and interpretation, involves the application of multiple criteria, often involves uncertainty, involves self-regulation of the thinking process, involves imposing meaning and finding structure in apparent disorder, and is effortful. Whereas, Zohar and Dori (2003) and Zohar (2004) state that higher-order thinking includes constructing arguments, asking research questions, making comparisons, solving non algorithmic complex problems, dealing with controversies, identifying hidden assumptions, as well as classic scientific inquiry skills. An understanding of chemistry principles in this study has therefore taken into consideration the notions of Resnick (1987) and Zohar and Dori (2003) as evidence of students’ ability to demonstrate HOTS regarding the ideas of chemical reactions.

Considerable higher-order thinking in chemistry is needed to build understanding of ideas of chemical reactions. To build a conceptual understanding of ideas of chemical
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reactions is a challenging process: students must integrate all the interactive, energetic and dynamic aspects of chemical reactions (Justi 2002). Chemical reactions can be classified into three different categories, viz. stoichiometry, thermodynamics and kinetics. This study looked at how students experience stoichiometry in terms of chemical reactions as this section poses many problems for students at first year level at the university in KZN. Evidence of the difficulties students have experienced with stoichiometry has been revealed in poor test and examination results in the past years 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 and Barakat (2003). Results from BouJaoude and Barakat’s (2003) and Agung and Schwartz’s (2007) 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.

In this study supporting deep understanding and HOTS 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 are believed to assist students begin to process information beyond the superficial level of delivering the ‘right’ answer. This is 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 organizers, such as concept maps, are suggested as ways to organize information and thoughts for better understanding. They help students’ link new information to their knowledge schema and promote interaction among students (Trowbridge and Wandersee 1998). Paired problem solving on the other hand, is a procedure, which is designed to capitalize on metacognitive learning, or the ability to clarify one’s thinking by explaining a concept or a procedure to another.

In this study, it is assumed that inquiry-based learning with appropriate pedagogical strategies can influence students’ deep understanding and higher-order thinking within the SI learning environment. According to the National Research Council (1996), scientific inquiry requires students to combine processes and scientific knowledge as they use higher-order thinking to develop their chemical understanding.

METHODOLOGY

As mentioned previously, this study is focussed on improving the quality of teaching and learning in chemistry education, through Supplemental Instruction and SI leader intervention. The use of interactive approaches to teaching and learning in SI was examined, focusing on developing deep understanding and higher-order
thinking skills in chemistry for first year engineers. A design research methodology was used to understand the first year engineering students’ engagement within the Supplemental Instruction environment.

This article is located within the interpretive paradigm because we would like to understand the engagement of the SI leaders in developing deep understanding and HOTS in stoichiometry in chemistry. It focuses on natural settings, within chemistry classrooms in this instance, and it allows multiple sources and multiple research methods, such as video-recordings, observations and focus group interviews.

This research explores improvement in educational practices, in light of students’ engagement within an interactive approach to Chemistry teaching and learning using a research design methodology. Wang and Hannafin (2004) define research design as follows ‘Design-based research is 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’. The aim of this research methodology is to understand not only the design solution but the design process. Design and research processes are integrated with the design research methodology.

Essentially this article will focus on three phases of the design research.

Phase one (SI leader training):

- Two SI leaders (recruited from fourth year Engineering students and post-graduates) were trained in a one week session by developing the SI learning environment.
- SI leaders were trained in effective study strategies, group dynamics (interactive teaching and learning strategies) and the facilitation of learning.
- It was emphasised that the role of the SI leader is not that of a lecturer, but rather to initiate group discussion and encourage the active participation of the first year engineering students.
- Further to the training, the SI leaders were required to attend a minimum of one lecture per week on the first year chemistry module which assisted in planning and preparation of the SI sessions and refreshing the SI leaders on chemistry concepts to be discussed.

The second phase of the design research was the implementation phase where SI leaders facilitated the SI sessions in attempting to develop deep understanding and HOTS in stoichiometry. The researcher served as a mentor in this study and the SI leaders met after each SI session to reflect on the session. It was at this forum that the design of the SI learning environment was redesigned to meet the needs of the first year engineering students. SI leaders were also involved in designing activities for the SI sessions with the assistance of the researcher, which we believed would
develop deep understanding and higher order thinking. This article therefore focuses on how this SI intervention programme impacted on what SI leaders did during the SI sessions in developing deep understanding and HOTS in stoichiometry.

**METHODS OF DATA PRODUCTION**

In this study fifteen SI sessions were observed over a period of ten weeks (one semester) and two SI leaders in two different first year engineering chemistry modules. The qualitative research method employed in the study was observations through video recording. The use of video-recordings helped to observe situations more than once.

An observation schedule was constructed that took into consideration three aspects: the Context of the SI session, Students’ Experiences during the intervention and the Content that was covered in stoichiometry. Questions pertaining to the context section covered the nature of engagement, issues of discussion, how participation took place, ethos and strategies to motivate learners. With respect to Students’ Experiences we examined the kinds of questions students were asking, whether there was a willingness on the part of the student to take on challenging tasks and further examined whether the SI leaders were engaging students in ways that provided the necessary support in developing deep understanding and HOTS. The Content section of the observation schedule covered stoichiometry and here the types of questions students asked in developing HOTS in stoichiometry were examined. We also looked at assessment techniques used and how spaces were created in terms of content to develop deep understanding and HOTS in stoichiometry.

Towards the end of the course students were asked to attend focus group interviews on a voluntary basis to ascertain factors that influenced student learning (third phase of the design research). The main aim of this article was to explore the ways in which the SI leaders were able to engage students in deep understanding and higher-order thinking skills in stoichiometry. Thus, to explore this aspect of the learning further, students were asked to describe the ways in which they felt the SI learning environment supported their learning.

**RESULTS AND DISCUSSION**

This study takes the form of observations of SI leader engagement in developing higher-order thinking skills and deep understanding of stoichiometry concepts. Statistical data from the observation schedule and qualitative data from the focus group interviews have been inserted selectively to estimate the potential measure of the level of student engagement in developing a deep understanding and higher-order thinking skills in stoichiometry.

The following themes were developed from the observation schedule: nature of engagement, types of learning activities, types of questions asked by students, nature of assessment techniques used and development of spaces for HOTS and deep understanding.
Nature of engagement

Figure 1 shows the different forms of engagement experienced by the students over the fifteen SI sessions observed and students’ preferences with respect to the different forms of engagement. These values were obtained from a frequency count of the three different types of engagement per session and an average of all sessions was found.

These results indicate a more collaborative approach to learning where students on average were encouraged to work in pairs for 39 per cent of the session and 36 per cent of the session was spent on group discussion. The extent to which a learning environment can engage learners is often seen as a strong indicator of the depth and scope of the learning that will occur (Trigwell et al. 2004).

Effective collaboration has the potential to help active participants improve their critical thinking as well as their skills in problem-solving, team working, negotiation, group decision-making and task management. 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 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 it can also help to stimulate activity and motivation among the group members. Teachers also need to encourage students to accept responsibility for their own learning (Goodrum et al. 2000). This perhaps is achieved in part by negotiating the setting of goals in a collaborative and supportive environment, so that students feel confident taking risks within the learning environment.
Types of learning activities
As an exploration of the capacity of such an environment to motivate and encourage learner participation, the different types of learning activities offered in a SI session were compared over all sessions that were observed. Table 1 shows the different types of learning activities students engaged in an SI session and the frequency of these activities over the fifteen sessions observed.

Table 1: Learning activities

<table>
<thead>
<tr>
<th>Types of learning activities offered to encourage participation</th>
<th>Number of Sessions</th>
<th>Percentage</th>
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</thead>
<tbody>
<tr>
<td>a. Group discussion</td>
<td>11</td>
<td>74</td>
</tr>
<tr>
<td>b. Individual presentations</td>
<td>15</td>
<td>100</td>
</tr>
<tr>
<td>c. Visual techniques</td>
<td>15</td>
<td>100</td>
</tr>
<tr>
<td>d. Paired problem solving</td>
<td>15</td>
<td>100</td>
</tr>
</tbody>
</table>

It can be seen that individual presentations, visual techniques and paired problem solving were techniques used in all SI sessions however, group discussions featured only 74 per cent of the time which was sometimes due to small number of students attending in which case they preferred to work in pairs or individually and in other instances students found it more comfortable talking to the person next to them than contributing to a group discussion.

Types of questions asked by students
To assess the development of deep 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 analyzed. The observation schedule data revealed that during the initial SI sessions on stoichiometry 72 per cent of the questions were based on procedural type questions for example: ‘How do we calculate the limiting reagent?’. A few developmental questions were asked which constituted 23 per cent of the questions asked for example: ‘Why do we calculate the number of moles of CaCO₃ twice?’ The remainder (5%) of the questions was administrative type questions for example: ‘How long do we get to work on this problem?’.

Towards the later part of the study it was found that 50 per cent of the questions asked were procedural and 48 per cent were developmental and a mere 2 per cent were administrative type questions. These results support the finding in Table 2 which indicates that practice and constant feedback play a major role in developing higher-order thinking skills. These results also concur with (Jos et al. 2005) who note 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 reorganization and restructuring of knowledge, so that students
are able to hypothesize, deduce, look for inferences and make improvements in their knowledge.

Table 2: Methods of high level skills development

<table>
<thead>
<tr>
<th>How do SI leaders attempt to develop high level skills?</th>
<th>% per session</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. training</td>
<td>23</td>
</tr>
<tr>
<td>b. practice</td>
<td>42</td>
</tr>
<tr>
<td>c. feedback of content knowledge</td>
<td>55</td>
</tr>
</tbody>
</table>

Types of assessment techniques used

There are various ways to assess higher-order thinking in the literature, one of them is open-ended assessment (Zohar 2004). Open-ended questions and probing questions have been used to assist the researcher and the SI leader to understand more clearly how students think, prior knowledge of students, and what understandings students gained during group discussion and oral presentation. Concept maps also provide a portrayal of an individual’s mental representation of a concept (Edmondson 2000).

Table 3: Assessment techniques

<table>
<thead>
<tr>
<th>Types of assessment techniques used by SI leaders</th>
<th>% frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Drawing concept maps</td>
<td>4</td>
</tr>
<tr>
<td>b. Informal Quiz</td>
<td>6</td>
</tr>
<tr>
<td>c. Asking Probing questions</td>
<td>58</td>
</tr>
<tr>
<td>d. Problem solving</td>
<td>40</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

It was found that asking probing questions (58%) was the most frequently used assessment tool used in all fifteen sessions to assess understanding as well as HOTS, this was followed by problem solving activities (40%) which involved students explaining their answers on the board, informal quiz (6%) and drawing concept maps (4%).
Development of spaces for higher order thinking and deep understanding

Figure 2 represents the observations of how SI leaders develop the spaces for higher order thinking and deep understanding in stoichiometry.

![HOTS Development Chart](chart.png)

1. asking higher-order questions  
2. engaging in activities that require higher order thinking  
3. asking open-ended questions  
4. instigate students to reflect on their own thinking  
5. provides good examples of how to transfer knowledge to other situations

Figure 2: Development of HOTS and deep understanding

One of the important aims of promoting engagement and interest in a learning environment is to promote the acquisition of deep rather than shallow knowledge and higher-order thinking skills (Biggs 1999). To gain some sense of the way in which the SI leaders promoted depth and breadth to student learning, we observed how the SI leaders developed spaces for HOTS and deep understanding of stoichiometry in the SI sessions.

It is evident that providing students with good examples and formulating links with other situations dominated the SI sessions in developing spaces for HOTS and deep understanding of stoichiometry. It also seems like reflective practices were encouraged as well as engaging in activities that required higher-order thinking for example students were asked to criticize statements with respect to stoichiometry or evaluate answers put on the chalkboard.
Factors influencing levels of student engagement
An important element of the study was to explore the ways in which the SI leaders were able to provide support for 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, student-focused activities and concept development.

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:

- 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.

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;
- to explore, question and research other alternates as a fundamental component of their learning.

Conceptual development
SI sessions require 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 recognized 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:
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- 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.

CONCLUSION

This article describes a study that explored how SI leaders engage first year engineering students in developing a deep understanding and higher order thinking skills in chemistry. The study explored the forms of engagement that the engineering students were exposed to in an inquiry based learning approach and the factors that were found to influence student engagement. The findings confirmed expectations that the inquiry based approach would engage learners as revealed by Biggs (2003) and Jose et al (2005) but revealed that student engagement coupled with constant feedback, practice in problem solving as well as developing spaces for HOTS and deep understanding in terms of scaffolds for learning and evaluations of learning all contribute to developing HOTS and deep understanding in stoichiometry.

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