Exploring the effectiveness of POGIL and Chemorganisers in foundation chemistry

A mixed methods study

Submitted in partial fulfillment of the degree MSc Science Education in the department of Chemistry in the Faculty of Natural and Agricultural Sciences at the University of Pretoria

CHRISTINE ELIZABETH MUNDY

2015

SUPERVISOR

Prof. Marietjie Potgieter

ABSTRACT

The extended BSc programme at the University of Pretoria was the context of this study; specifically, students enrolled in foundation chemistry. This study was aimed at improving teaching and learning at this level, by implementing pre-existing education interventions, Process Oriented Guided Inquiry Learning (POGIL) and the use of the Chemorganiser. Themes chosen for the interventions were the ***mole concept and stoichiometry*** and ***redox reactions***, as these have been identified as common areas of difficulty in Chemistry (Johnston, 2010).

POGIL required students to take on well-defined roles and work in groups on specially designed worksheets (Farrell, Moog & Spencer, 1999). Chemorganisers were A4 sheets which broke down topics by highlighting key concepts and provided students with a clear strategy on how to solve problems (Reid and Sirhan, 2001). Chemorganisers were used individually after a class discussion thereof. Different theoretical frameworks underpin the two interventions: POGIL is constructed around "The Learning Cycle" in which students explore data, invent concepts and apply these concepts to problems (Farrell et al., 1999). On the other hand, "Cognitive Load Theory" was the motivation behind the development of Chemorganiser in that content is "chunked" to become more manageable for the students (Kirschner, 2002).

The POGIL intervention was implemented in a group of approximately 50 students, likewise with the Chemorganiser intervention, the remainder of the students on the course acted as a control. The Integrated model of School Effectiveness (Scheerens, 2004; 1990) served as the theoretical lens for the study. The effectiveness of each intervention was explored using the classroom variables of productivity, student preference and opportunity to learn along with the output of student performance. Mixed methods, including observations, focus group interviews, student questionnaires and student performance data, were used.

During the first year of implementation the Chemorganisers were well received by students. Increased classroom participation and confidence was noted along with stable levels of attendance. Students requested the inclusion of more challenging content. This intervention did not affect the time allocated for the tutorials and was easy to implement. Students performed better on average than their counterparts; a highly statistically significant difference was noted ($p<0.0001$).

Contrary to evidence for the success of POGIL elsewhere, students who experienced this intervention were dissatisfied and class attendance dwindled. Students required twice the time to be spent on the same content. Students often found group work challenging and lacked confidence in their preparedness for assessment.

The interventions were refined before implementation in the second year. The content integrity of each intervention was preserved with adjustments to the POGIL group organisation. Data collection methods remained the same. Further improvement was noted in student performance for the Chemorganiser group. All other findings remained similar for the Chemorganiser group. The POGIL intervention was far better received by the students; students were at ease in groups of their own choosing. Students attended tutorials and worked productively. POGIL students performed better in assessment in year 2, their performance being equivalent to that of the control group.

The findings of the study suggest that Chemorganisers created an effective learning environment, through the active reduction of cognitive load on the students. The effectiveness of POGIL was improved in the second year. That is, the challenges of group work could be managed effectively through careful re-implementation. For the purpose of full scale implementation, the Chemorganiser was judged to be the intervention of choice.

PLAGARISM DECLARATION

I declare that the dissertation which I hereby submit for the degree of MSc Science Education at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at another university. Where secondary material is used, this has been carefully acknowledged and referenced in accordance with university requirements. I am aware of university policy and implications regarding plagiarism.

SIGNATURE:.. DATE: 15 July 2015

C E MUNDY

AKNOWLEDGEMENTS

Firstly, I would like to thank the University of Pretoria, for the opportunity to study and for the provision of meaningful, although challenging education modules. Next the Department of Chemistry, for the appointment of myself as an educator, and for their keen interest in and support of chemistry education research.

My colleagues, John and Jane, first and foremost for acting as external observers, and for offering their opinions, support and help with the invigilation of tests. My course co-ordinator, Dorine Dikobe, for her understanding and flexibility.

A special thank you to the Statistics Department, particularly Joyce Jordaan and Fransonet Reyneke, for their swift and meaningful contributions to the quantitative portion of this study.

I am eternally grateful for my supervisor, Prof Marietjie Potgieter, for her encouragements and feedback. For allowing me to grow as a researcher, without dominating my views. And for giving me the opportunity to present my research to the HELTASA and SAARMSTE communities.

I am thankful for the encouragement and correspondence I had with Prof Norman Reid, and for the access to the Chemorganiser archives. Another external party, Dr Angela Roche, with her many years of experience, who took the time out of her teaching schedule to closely examine my intervention materials.

A big thank you to all the students who participated in this study, especially those who took the time out to give me their opinions. Thank you again to my past, present and future students who inspire me to be a better educator.

Finally, my immediate family for their patience, support and (frequent and sometimes inspiring) ideas. I would like to particularly mention the illustrations which helped so much at conference presentations. And lastly, but most especially, my husband Kyle, who has helped in so many ways…

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CHAPTER 1: INTRODUCTION TO THE STUDY

1.1 INTRODUCTION

This chapter begins with the researcher's initial motivation for this study. The chapter broadens to explain the worth of such a study by providing a context specific background to both the study and the participants. After the rationale has been discussed, the first chapter closes with a concise aim and accompanying research questions; followed by a brief outline of the further chapters in this report.

1.2 MOTIVATION FOR THE STUDY

I am in the early stages of my academic career, lecturing chemistry to first year extended programme students on a satellite campus of the University of Pretoria. A drive towards bettering educational practices in the sciences is present internationally, an example is the Trends in International Mathematics and Science Study (TIMSS), in which trends in science and mathematics achievement can be tracked and compared (TIMSS and PIRLS International Study Center, 2013). Studies of this nature and popular interest in the educational field have inspired my own educational ambitions. I hope that by engaging in modern alternative educational innovations, I will be able to improve and refine my own teaching methods; and as such, improve the students' learning experience in chemistry.

I acknowledge that careful consideration is required when selecting new teaching approaches as they will directly impact on the students' learning; it is also agreed that not every student benefits from the same teaching style. And even though innovations may be highly successful in the developed countries in which they were established, this is not necessarily the case within the specific context of a South African extended degree programme. For these reasons, it would not be sensible to implement selected educational innovations on a full scale, but to pilot the innovations in small themes. Recommendations of larger scale adoption may only be made after cautious evaluation of the educational approaches.

1.3 BACKGROUND AND CONTEXT OF THE STUDY

Extended, bridging and foundational programmes have become prevalent in South Africa to increase graduate numbers by offering additional academic support either by extending the duration of a degree or by introducing a foundation year which acts as a gateway into mainstream programmes (Moolman, 2013). At the University of Pretoria, the notion of an extended programme is synonymous with the BSc Four Year Programme – that is, the extension of learning forms part of the degree and is not a separate qualification.

Students who chose to be enrolled in an extended programme, do so for a variety of reasons: low achievement at high school level as a consequence of a lack of personal motivation, inadequate teaching or other socio-economic factors like the lack of facilities or learning materials in the classroom. A small portion of students are allocated to the extended programme degree due to limited places available in mainstream degrees. These reasons often contribute towards a gap between what learners learn at high school level and the skills required for students to achieve at tertiary institutions (Scott, Yeld and Hendry, 2007; Smith, 2007). The challenge in extended programmes is to close this gap whilst being mindful that students may have a poor grasp of subject matter or may be weak in their conceptual development.

The BSc Four Year Programme, offered by the University of Pretoria, is crafted (Smith, 2007) to allow for prolonged and intimate exposure to content, in that the content of a first semester of a main stream course is dealt with over the progression of 18 months or three semesters. The first two semesters, in which this study takes place, are delivered on the Mamelodi campus – a satellite campus, isolated somewhat beneficially from the distractions of main campus life (Engelbrecht, Harding and Potgieter, 2014). The extended time period allows high school knowledge to be revisited and strengthened, creating a solid foundation for tertiary chemistry. The extended time also affords the opportunity to thoroughly engage with new concepts and content presented at the tertiary level, which is not always available in mainstream courses.

1.4 STATEMENT OF THE PROBLEM

There has been a definite movement away from transmission teaching, often referred to as traditional teaching, in which learning was viewed as the transfer of knowledge from the teacher to the learner. There are multiple reasons for the shift away from transmission teaching: firstly, it is seldom that all the information is transferred intact (Cracolice, 2005) due to the individual nature and experiences of the learner acting as an information filter. Secondly, transmitted information holds less meaning for the learner and as such may not be successfully retained in the long term memory (Johnstone, 2010). Transmission teaching also does not allow for the development of in-depth conceptual understanding (Mazur, 1997), nor does such a teaching style accommodate the variety of leaning styles which students bring to the classroom.

The general realisation that, "teaching as one was taught" (Cracolice, 2005, p. 12) allows no room for improvement in teaching styles; has prompted the conception of many new styles and approaches to learning over the past decades. It is the duty of educators to optimise the learning experience, and thus the potential success of the learners or students.

Another important factor in this study is the nature of the students on the campus: most of the students can be viewed as weaker performers. Weaker students often have a flawed concept foundation – gaps in knowledge or misconceptions – and it is the aim of an extended programme to address such gaps and as such enable "the student to attain a deeper understanding of the subject knowledge" (Smith, 2007, p. 5).

On the extended programme, students may not only have weaker content knowledge but poor performing students have also been observed to lack confidence in their own abilities (Greenbowe, 2013). Ambrose, Bridges, DiPietro, Lovett and Norman (2010, p. 16) describe such students as fragile. Fragile students would like to engage in learning because they see the value in the situations but do not, due to doubts in their own capabilities or a low self-efficacy. Another characteristic of a fragile student, according to Ambrose et al. (2010) is that the student perceives a lack of support in the learning environment. These factors could possibly explain the behaviour of some extended programme students in that students hesitate to own knowledge and tend to withdraw from expository classroom situations.

A lack in academic language proficiency has been highlighted as a factor of under-preparedness in extended programme students (Scott et al., 2007, p. 44). Present in, but not exclusive to, the extended degree programme is a large number of second language English speaking students. The mastery of English is varied among students despite courses offered by the University of Pretoria. Some students do lack confidence in their ability to communicate, and as such do not actively engage in learning opportunities (Tsui, 1997). Difficulties for English second language students in a learning environment can be seen in three layers: as aforementioned, language may be an obstacle in grasping concepts, especially when the student disengages to self-protect (Ambrose et al., 2010). The next two layers deal with assessment, do the students fully understand the questions asked and can the students fully express their answers? Wilkinson and Silliman (2001, The Origins of Classroom Language Research, para. 2) highlight this difficulty in the statement: "Accurate assessment of their achievement is unlikely, since access to their knowledge is predicated on optimal communicative performance". These three layers crystallise the fear of many educators who deal with English second language students - is subject competence being tested or is it an assessment of the students' language competence?

To conclude, many challenges arise in an extended programme classroom and are highlighted by the implications of the statement by Johnstone (1997, p. 264) "The discomfort of something that does not make sense often leads to the rejection of the new idea". If 'sense making' is hindered by poor teaching methods, a concept gap, poor self-efficacy or a language divide, meaningful learning will not occur.

1.5 RATIONALE FOR THE STUDY

The first year of the extended programme is the first phase of a student's tertiary academic career. Setting the study within this phase allows for any benefits to carry through for the duration of their studies. "At no time is support, in particular academic support, more important than during the critical first year of college or university when student success is still so much in question and still malleable to institutional intervention" (Tinto, 2012, p. 5). The effects of an improved learning experience are anticipated on two levels: non-cognitive gains in the students' academic self-concept or self-efficacy, and cognitive gains, which include the development of academic skills such as problem-solving ability, study skills and critical thinking.

Many students entering tertiary education do not arrive with skills that were assumed to be present in the past and are often accused of academic deficiencies (Scott et al., 2007). This study allows for the prospect of working with such students in a different way: in exploring different educational designs, students may be equipped to reach their potential.

Students entering the extended programme often do so with lower marks in mathematics and science than that of their main stream counterparts (Scott et al., 2007): thus, their low "pre"-tertiary education achievement leaves a large gap between the maximum possible achievements of the students (Hake, 1998). Thus, this study offers the distinct opportunity to benefit weak students who have a large margin open for academic improvement.

Chemistry is widely considered a gateway subject at tertiary level. CMY 133 and 143 are considered High Impact Modules (HIMs) at the University of Pretoria. Chemistry is a core first year subject in most BSc degrees and chemistry often acts as a prerequisite subject for the advancement of a student into the second academic year. Intervening in an early stage may allow for stronger conceptual foundations to be built in chemistry. These foundations are an essential component to the basic scientific literacy of any BSc student. Strong conceptual foundations will also be supportive to any student pursuing a degree in chemistry or alike.

The specific nature of the students in an extended programme was taken into account when selecting the international education innovations. In this study, two approaches to teaching will be explored: firstly the popular shift towards Process Oriented Guided Inquiry Learning (POGIL) and, secondly, The Chemorganiser, which embodies the idea of providing students with a summarised mental framework for every section covered.

The first approach chosen was that of Guided Inquiry or Inquiry Based Learning (in the form of POGIL), as it represents a **revolution in teaching and learning** in that the educator is shifted from the role of an instructor into that of a guide (Cracolice, 2005; Farrell, Moog and Spencer, 1999). Additionally, the popularity and the publicity attached to this radically new approach; along with its numerous successes, has endeared the approach to the researcher.

The use of the Chemorganiser, as it still complements traditional teaching styles, is the other extreme and as such, begs for comparison to Guided Inquiry. This second approach has been seen to benefit students with the widest margins open for academic grade gains and therefore has an added advantage in extended programme environments (Reid and Sirhan, 2002).

An essential component of the rationale behind the study was to ascertain the degree to which successful international education ideas are transferable into a local context. It must be noted that the notion of a preferred educational approach hinges on the premise that by taking on a new approach, a positive impact will be realised in terms of student performance and the overall quality of the learning experience. Thus, the question is posed, if the gains of innovative approaches are not significantly different from those of a traditional approach, is it indeed worthwhile to pursue them? Reid (2008, p. 58), wisely stated, "Far too much curriculum construction, textbook writing and teaching approaches are based on assertion and opinion," not grounded in research, results and science – which are the fundamentals of this study.

1.6 AIM OF THE STUDY

This study involved the implementation of two educational innovations within a specialised context. The primary aim of this study was to fully investigate each educational approach, POGIL and the Chemorganiser, in terms of effectiveness. Effectiveness was gauged by analysing the strengths and weaknesses of each approach based on a fixed set of criteria. Multiple ways or methods were used to gather data on each approach, for example, the use of focus group interviews, observations and test score analysis. This has expanded the research experience set of the researcher.

1.7 RESEARCH QUESTIONS

During the course of this study, the researcher undertook to attempt to answer the following primary research question:

1. How effective are each of the two educational approaches, POGIL and the Chemorganiser, in the context of foundation chemistry?

The primary question will be answered through the following secondary research questions:

1.1. How do the approaches influence student performance?
1.2. What are the impacts on the students' opportunity to learn within each approach?
1.3. What influence does each approach have on productivity, both inside and outside the classroom?
1.4. How are the approaches received by the students?

1.8 OVERVIEW OF THE STUDY

The researcher took a pragmatic stance and embarked on mixed methods research in an effort to best answer the diverse research questions listed above. The data collection methods used in this study included observations, focus group interviews, student performance in assessment and a student questionnaire. The study was scheduled to be repeated over two years, with each intervention (either POGIL or the Chemorganiser) implemented in pre-existing groups of fifty students. Therefore the two groups of fifty students constituted the experimental groups in a given year and the remainder of the students registered on the course acted as the control group. Due to unforeseen results after the first year of the study, the interventions had to be refined before reimplementation in the second year of the study.

1.9 SEQUENCE OF THE RESEARCH REPORT

The report has opened with an introduction to the research, the motivation for the study and the general explorative direction it will follow. The second chapter creates insight into each of the educational approaches by providing a thorough literature review, and, closes with a discussion of the Integrated Model of School Effectiveness (which was chosen as the lens of this study). In the third chapter, Research Design and Methodology, the practical details of the study were proposed and substantiated. Ethical considerations were also outlined in Chapter 3. Chapter 4 acted as a bridge between Chapter 3 and Chapter 5, by outlining the provisional findings and proposed refinements. The research report culminated in the fifth chapter, in which the results of the study were presented and discussed. The closing chapter in this report consisted of concluding remarks and recommendations for further research. Appendices can be found at the back of the report, providing learning materials utilised during the study and all documents used in data collection.

1.10 SYNTHESIS

In this chapter, the extended degree programme was discussed as an area which provides opportunities for the improvement of teaching and learning, especially as academic gains and self-efficacy gains may be carried through for the remainder of a student's tertiary academic career. The motivation for such a study was a personal one in which the researcher aimed to identify and implement an educational approach which was the most effective for the students given the context of the study. The specific measures of effectiveness are discussed in the following chapter along with a more detailed description of the two interventions, POGIL and the Chemorganiser, which were briefly mentioned in this chapter.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

The two educational approaches that were used in this study are POGIL and the use of the Chemorganiser. In this chapter these two innovations are examined: to start with, the educational and psychological theories underpinning each approach are discussed, so that the approaches themselves can be fully appreciated. Next, the tools of each educational approach are addressed: POGIL Guided Inquiry Worksheets and the Chemorganisers themselves. A brief comparison of two approaches follows, in order to provide a summary which highlights the main differences in the approaches' principles and practical implementations. The chapter concludes with a discussion of a model which will be used to compare the two educational approaches in terms of instructional effectiveness.

2.2 PART I: POGIL AND ITS SUPPORTING THEORIES

2.2.1 CONSTRUCTIVISM

Constructivism is a theory of knowledge which has an influence upon education (among other fields). Such a theory, within the context of science education aims to unify learning with the nature of science: "Genuine scientific knowledge (is) revived when inquiry (is) adopted as part of its own procedure and for its own purpose" (Dewey, 1938, p. 94). Scott, Asoko, Driver and Emberton (1994, p. 219) explain this as a new way of seeing which allows the student to be assimilated into the scientific community. The following definition is useful, "Constructivism is a philosophical view on how we come to understand or know" (Savery and Duffy, 2001, p. 1). The theory of constructivism can be broken down into three propositions:

1. **Understanding lies in interactions with the environment** (this is the primary notion underlying constructivism). Humans are not isolated, we are connected to our environment, both socially and physically (Dewey, 1938).
2. **Cognitive conflict or puzzlement stimulates learning and determines the organization and nature of what is learned.** Learning is provoked or precipitated by situations, it is not considered to be spontaneous (Piaget, 2003, p. S8; 1964).
3. **Knowledge evolves through social negotiation and through the evaluation of the viability of individual understandings** (in short, "social constructivism"). Piaget (2003, p. S13; 1964) refers to this negotiation as the re-establishment of an equilibrium, which is an active process known as self-regulation. This evaluation or re-establishment is based on an initial

dissatisfaction with existing student conceptions (Bodner, Klobuchar and Geelan, 2001, p. 1117).

Such a theory, or point of view, has influences upon education in terms of lesson planning and the types of activities and materials used. Scott et al. (1994, p. 208) highlights that "careful analysis (by the educator) of possible routes from student starting points to the intended learning goals is necessary". A concern regarding constructivism in the classroom has been raised by Bodner et al. (2001, p. 1114) in that if knowledge and understanding is constructed, the student cannot be wrong; "Truth is what he (the learner) is able to accept" (Schwab, 1957, p. 41). This obviously has significant impacts on assessment if the educator has not anticipated such answers or possibilities beforehand and has not adjusted the lesson accordingly.

2.2.2 GROUP WORK

Group work is a core component of the theory of social constructivism, and has various benefits, "Collaborative groups are important because we can test our own understanding and examine the understanding of others as a mechanism for enriching, interweaving, and expanding our understanding of particular issues or phenomena" (Savery and Duffy, 2002, p. 2). Webb (1989, p. 24) states that an advantage of small group learning is that learners may effectively help one another. Webb (1989, p. 24) lists the qualifying conditions of beneficial or helpful group learning as follows:

1. The help must be relevant to the particular misunderstanding or lack of understanding of the target student
2. It must be at a level of elaboration that corresponds to the level of help needed
3. It must be given in close proximity in time to the target student's error or question
4. The target student must understand the explanation
5. The target student must have an opportunity to use the explanation to solve the problem
6. The target student must use that opportunity.

Schwab (1957, p. 41) explains the necessity of group work as opposed to individual efforts, which is highly applicable in a constructivist educational context, "Group dynamism, as a doctrine of education, begins with the point that a very large part of human work in our society (and perhaps in all societies) takes place in groups. The doctrine then points out that such work not only takes place in groups, but by the group as a group, rather than by individuals operating in their individuality."

Whether done on a small or large scale, grouping can be divided into two different types: homogenous and heterogeneous. In education, grouping is often based on achievement or student ability, ideally such grouping should provide students with equal educational opportunity (Esposito, 1973). Homogeneous ability grouping refers to organising students into groups of similar achievement levels. One of the main benefits of such groupings is that students are able "to advance at their own rate with others of similar ability" (Esposito, 1973, p. 166). Homogeneous grouping is not often employed in small grouping scenarios as it is deemed unrealistic, "most adult life experiences do not occur in homogeneous settings" (Esposito, 1973, p. 166). On the other hand, heterogeneous ability groupings occur in two ways: groups are either assigned randomly on deliberately (as in the POGIL approach), resulting in group members of mixed abilities.

Small group learning is often employed as student-to-student interactions often increase achievement because of more intense information processing (Springer, Stanne and Donovan, 1999). Small scale heterogeneous ability grouping is more popular in education as members are able to help each other and reinforce their own conceptions and knowledge basis, whereas homogeneous grouping may create a competitive social environment or may be demotivating in terms of perceived academic ineptitude (Esposito, 1973; Springer et al., 1999). However, it is unlikely that any type of grouping will be completely neutral in terms of social and emotional impacts. Wilkinson (1990) also mentions "stability of groupings, and the permanence thereof, to have varying impacts on students and learning.

2.2.3 INQUIRY-BASED LEARNING

The use of questions, to seek the answer or to create a concept, is the crux of Inquiry-Based Learning or IBL (The Academy of Inquiry Based Learning, 2013; Exline, 2004). IBL, when employed as a teaching method, aims to generate concepts and increase students' understanding. IBL does not relay facts to the students, as in more traditional educational practices, as if students are empty vessels (Abraham, 2005). There is a greater emphasis in IBL on "how we come to know" and less on "what we know".

As mentioned above, questioning is used in IBL, but the questions are not always posed by the instructor, often students are encouraged to ask questions of the instructor once they have been exposed to a new scenario or to data they do not fully understand. It is then a question of who steers the ship, the instructor or the students? Different degrees of freedom exist within IBL, and it is the responsibility of the instructor to monitor and maintain the desired learning environment (Abraham, 2005). There is a range of IBL designs or levels which vary in whether the problem, procedure and solution are given to, or constructed by, the learner (Fay, Grove, Towns, and Bretz, 2007). For the purpose of this study, this range is simplified into two main types. **Open inquiry** (in which the students steer the classroom discussions and activities) and **guided inquiry** (in which the decision-making for the course of the lecture is shared between the instructor and the students) (Abraham, 2005, p. 48).

The role of the instructor is subtle in both methods – even if it is not outwardly clear within open inquiry. The designs of the lesson and outcomes are the territory of the instructor and must be very well planned to eliminate the scenario in which students' *fumble in the dark* and waste time with off-the-topic questioning. This is easier to avoid with guided inquiry, as the instructor has the ability to actively shepherd the direction of the lesson (The Academy of Inquiry Based Learning, 2013).

2.2.4 THE LEARNING CYCLE

Inquiry-based learning shares common features with the theoretical framework of the Learning Cycle: questioning, exploration and probing of the surroundings are used as a basis for conceptual development. Abraham (2005) neatly states that through IBL students are in situations where learning mimics the nature of science itself. One of the facets of science is the "independent discovery of knowledge" and it is maintained that if students construct knowledge and concepts for themselves, it will hold a greater meaning for them and hence be retained in a more permanent manner in the mind of the learner (Abraham, 2005, p. 41). Meaningful learning, compared to rote learning, has been seen to provide the student with an "intrinsic satisfaction", thus reinforcing a positive attitude to the subject material, hence this method has potential qualitative and quantitative benefits for student learning (Reid, 2008, p. 55).

The Learning Cycle began in the 1960's as a psychological theory which aimed to rationalise how students learn (Cracolice, 2009). There are three core, or central, phases in the Learning Cycle, however, five phases have been identified when implementing the Learning Cycle (Cracolice, 2009). The three core phases of the Learning Cycle form a concise theoretical structure and are referred to more often in literature. For this reason, the five phases of *engage, explore, explain, elaborate* and *evaluate* will not be discussed in depth but attention will be paid to the three core phases (Cracolice, 2009).

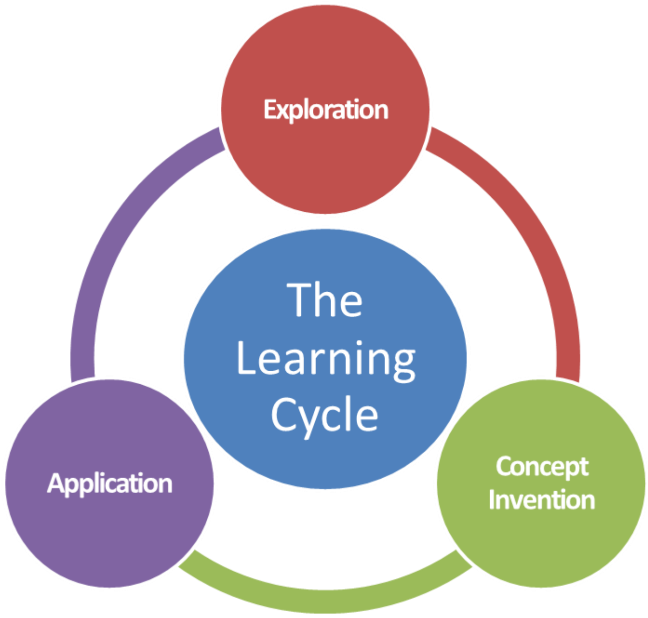

Figure 1. The core phases of the Learning Cycle

In order to fully appreciate the three core phases of the Learning Cycle (see above Fig. 1), and how they interlink one must acknowledge that such a cycle has a thrust, and that thrust is the "data-driven" approach that the Learning Cycle has cultivated in student centred inquiry based teaching (Abraham, 2005). What is meant by this notion is that the first stage, ***exploration***, is based on analysing data (whether the data is given or collected makes small difference except in the case of time management and lesson planning). The investigation or probing of such data prompts students to enter the second core phase of ***concept invention***. In this phase the learner finds patterns in the data and in doing so creates new concepts for themselves, in other words, students draw their own conclusions from the data (Abraham, 2005). Personal conclusions may be potentially problematic as misconceptions may arise but through the guidance of an instructor, through correctly devised learning materials or through group interactions; misconceptions may be resolved before they are applied (Farrell et al., 1999).

After the discovery of trends and concepts, the students employ the new knowledge gained by applying it; the third core phase is thus aptly titled ***application*** (Abraham, 2005). There are a variety of methods mentioned by Cracolice (2009, p. 26) which can be used to oblige student application or aid the extension of the concept they have built. Opportunities for application include homework problems, laboratory exercises and questions which prompt the students to link the new concept with their own pre-existing knowledge. In this final phase, there is a marked change in the manner in which students use data – initially, students were using an inductive approach to the data: they drew general conclusions from a specific data set. However, in the ***application*** phase, students take the general concepts that they have formulated and apply these concepts in other scenarios, that is they approach problems in a deductive fashion (Abraham, 2005).

2.2.5 INTRODUCTION TO POGIL

POGIL, or Process-Oriented Guided Inquiry-Based Learning, is a teaching and learning strategy which begun in 1994 in college chemistry in the USA (POGIL, 2012). The POGIL approach is very different from the structure and ideas of a traditional education environment and has received much attention in academic circles due to the success of students in POGIL courses. Brown (2010, p. 153) notes that "implementation of POGIL into a course is not, however, an effortless proposition" as it is so different from traditional classroom situations.

Active learning differs from traditional learning, as it is defined as activities used in the classroom which directly involve students in the learning process. POGIL is thus a form of active learning, specifically Problem Based Learning, which overlaps with both collaborative and cooperative group learning (Hein, 2012). Problem Based Learning requires "significant amounts of self-directed learning on the part of the students" (Prince, 2004, p. 223), likewise this is true for POGIL. Smith, Sheppard, Johnson and Johnson (2005, p. 89) describe Problem Based Learning in much the same terms as the Learning Cycle: a problem is posed, students identify what they need to know, they learn it and then apply it.

Hanson (2006, p. 31) draws attention to several cases of remarkable student achievements in terms of improved grades. In one such case, after a POGIL intervention, a considerable improvement in the final exam marks of first year chemistry students was seen: before POGIL was used, data was collected for ten years (1994-2003) and the average grade was 55.5% for those ten years. After initiating POGIL in 2004 the final exam average increased to 68.5% which was significantly higher than any mean result achieved between 1994 and 2003. It must be noted that the same assessment instrument was used for the duration of the 11 year study.

Academic gains in terms of grades are not the only reason why POGIL is so popular (Project Kaleidoscope, 2008). Farrell et al. (1999) found that student attrition, or the withdrawal of students from a course before writing the final exam, was reduced after implementing POGIL. In an eight year study, the average attrition was seen to decrease from 9.3% of enrolled students who discontinued the course (1990-1994) to only 2.3% (1994-1997).

Not all of POGIL's benefits are quantifiable in terms of statistical measures. Nor are such benefits the usual or expected objectives of a traditional chemistry course. Additional benefits include improved group work skills through student engagement in collaborative learning. Secondly, the roles assigned to the students improve their professional skills, such as public speaking or time management, in preparation for the workplace. It has also been found that most students enjoy POGIL more than traditional lectures (Lewis and Lewis, 2005). Moog, Creegan, Hanson, Spencer, Straumanis, Bunce, and Wolfskill (2009, p.98) discuss a qualitative study done in organic chemistry in which 688 students from six institutions responded to the statement, *"I would* ***recommend*** *the method of teaching used in this course to a student taking this course next year."* In the Fig. 2 below, the distribution of student responses to a closed 5 point Likert scale can be seen. 30% of the 307 students being taught organic chemistry with the traditional lecture approach would not recommend it; the assumption is that these students had a negative view of traditional lectures for one reason or another (Moog et al., 2009). When compared to the students enrolled in POGIL organic chemistry, the vast majority of the students approved the use POGIL and only 6% of the students can be seen to harbour some form of negative emotions towards the intervention. Smith et al. (2005, p. 92) also concludes that learning of this type should "promote more positive attitudes towards learning".

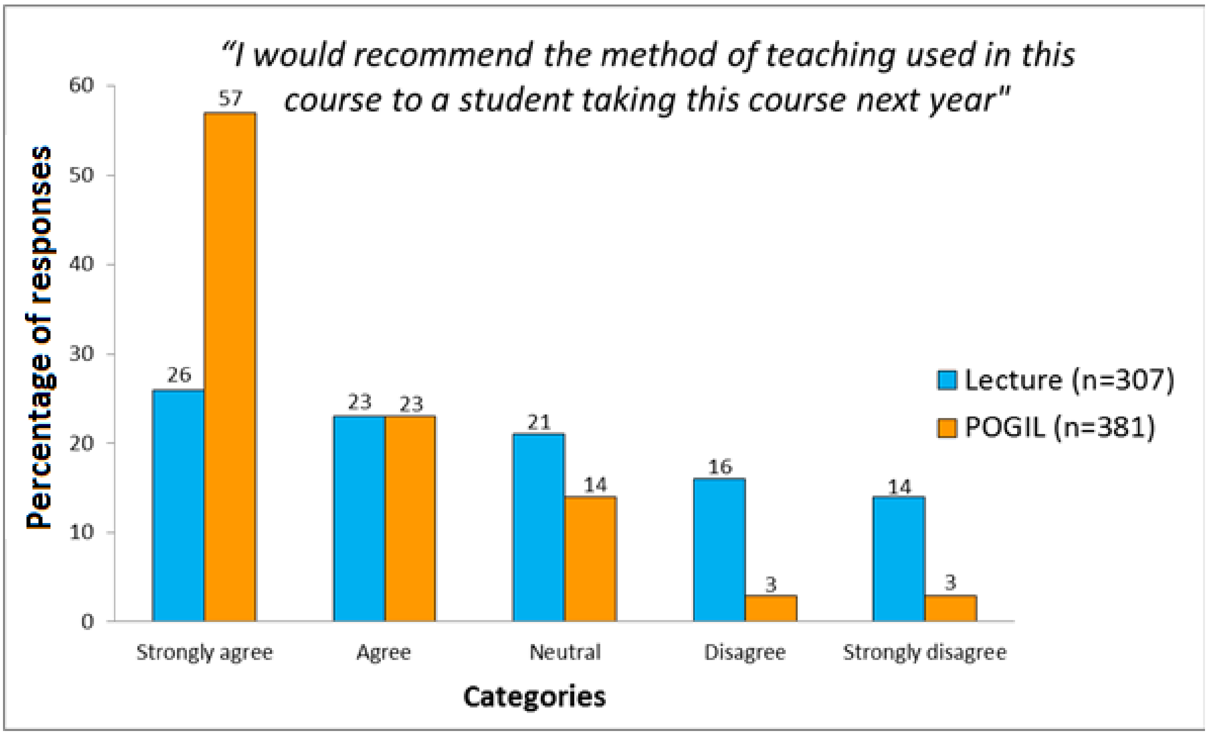

Figure 2. Distribution of responses to an anonymous student survey, adapted from Moog et al. (2009, p. 98).

2.2.6 IMPLEMENTATION OF POGIL

POGIL aims to impart professional skills to students through the group activities they employ and the special roles within the group (POGIL, 2012). Brown (2010, p. 150) refers to these as "noncontent skills". In a POGIL classroom students are divided into groups of 3-5 students and each student has a particular role to play within the group, depending on the class activity and size of the group, students may be allocated more than one role.

Table 1. Rotating roles of students in a POGIL classroom

Role	Responsibility
Manager	Time keeping Making sure the group stays on task The only member to communicate directly with the instructor Ultimately responsible for the group work
Recorder	Also known as the scribe Records the group observations and answers for the group Efficient and legible
Technician	Any technical skill or any calculation is performed Proficiency with calculator
Reflector/strategy analyst	Observes the group throughout the session Summarises novel concepts and content students discovered Notes group dynamics Mentions any shortcomings within the session Reflections are not shared with the rest of the group members
Presenter	Shares the findings of the group with the class as a whole at the end of the session Must use expertise necessary for public speaking

POGIL seeks to allocate roles to students in assigned heterogeneous groups. The rationale behind such a grouping is that "If lower-achieving students are in a group with higher-achieving students, the lower-achieving students can work in an environment where they are challenged with problems that require higher-level thinking. Furthermore, the higher-achieving students can be challenged to teach the lower-achieving students, which is a very different challenge than most students face." (Gulacar, Eilks and Bowman, 2014, p. 966). It is also assumed that through such interactions, students will develop positive relationships with other students (Hein, 2012, p. 860).

2.2.7 GUIDED INQUIRY WORKSHEETS

Farrell and Moog, designed and implemented Guided Inquiry Worksheets in 1997 for an American first year chemistry course, which has since been compiled into a workbook (Farrell and Moog, 2008). These worksheets were crafted to comply with the core phases of the Learning Cycle along with constructivist principles – in that the students actively build their knowledge basis for themselves (Farrell et al., 1999). POGIL has become a popular means of a non-traditional approach to student learning in the USA and is beginning to disseminate internationally. The way in which the Guided Inquiry Worksheets were fashioned enabled them to become streamlined with the POGIL approach in that no formal lecture takes place and students are divided into groups of about four to five learners – each with their own role and responsibility within the group. As a group, students work together on the worksheets, guiding each other (Farrell and Moog, 2008).

The groups are assigned randomly at first and once more information is gained on the students' academic performance, the groups may be restructured to be representative of the class performance (Farrell et al., 1999). The frequency of allocating students into new groups is variable, however, their roles within a group should change on a daily basis. There are five main roles within the group: *manager, recorder, technician, reflector* and *presenter*. Such changes in role are done for the benefit of the students, enabling them to develop confidence in a variety of professional and life skills (Farrell et al., 1999).

The role of the instructor is de-centralised in comparison to the traditional role of lecturer. The approach is now student-centred, with the instructor moving among the groups, listening and observing, discreetly evaluating **only** the students' participation (Farrell et al., 1999). Thus, the bulk of the role of the instructor is atypical, however, at the beginning of the class the instructor presents the students with a short quiz which should give "immediate feedback on how well the concept was learned" during the previous class. This quiz allows the instructor to address any issues in a one minute recap before the students regroup and begin on the assigned Guided Inquiry Worksheet (Farrell et al., 1999, p. 571).

Now that it is clear how the worksheets were used, more care can be taken in analysing the worksheets themselves. At first glance it can be seen that there is a neat parallel between the three core phases of the Learning Cycle and the three basic parts of the Guided Inquiry Worksheets. Such a parallel is shown in Fig. 3, by colour-coding the parts of the worksheets with the same colours used for the phases of the Learning Cycle in Fig. 1.

Models and/or information is the first part of the worksheet in which students are presented with data which can be in the form of a figure, an equation, a table, text, or any combination of these. The data is ***explored*** by the students and as such the data should be able to provide the starting block for the development of a chemical concept (Farrell et al., 1999, p. 571). In the second part of the worksheet, the students are aided in ***concept invention*** by ***critical thinking questions (CTQs)*** which are deliberately designed to help the students find patterns or relationships in the data and thus draw conclusions in the form of new chemical concepts (Farrell et al., 1999). The final part of the worksheet is ***application***; this part is not done in class but is prescribed as homework (often from the textbook). In this manner students can individually apply what they discovered as a group (Farrell et al., 1999).

Figure 3. The connection between the sections of the Guided Inquiry Worksheets in the same format as Fig. 1.

2.3 PART II: THE CHEMORGANISER AND ITS SUPPORTING THEORIES

2.3.1 INFORMATION PROCESSING MODEL

The Information Processing Model is based on the pursuit of cognitive psychology to understand memory (Huitt, 2003). Atkinson and Shiffrin (1968) proposed the Stage Model of Information Processing, which is the backbone of the Information Processing Model as it is now known, in order to explain "process(es) by which information is stored in, and retrieved from, long-term memory" (Shiffrin and Atkinson, 1969, p. 179). Baddeley and Hitch (1974) proposed an alternate model, in which the "functional importance of this system, as opposed to its simple storage capacity" was accentuated (Baddeley, 2002, p. 85). This multicomponent model of working memory, has become dominant in the field; Baddeley (2002, p. 95) confirms that such a model, although improved over time, is still functioning or "working" within current cognitive research.

A far less complex version of the model was proposed by Johnstone (1997, p. 263). This version, simply known as the Information Processing Model, was developed to understand memory and the assimilation of knowledge in the context of **learning environments** or **education**, and as such is relevant to this study. A representation of Johnston's model is given below, Fig. 4, the model has been supplemented by annotations by the researcher

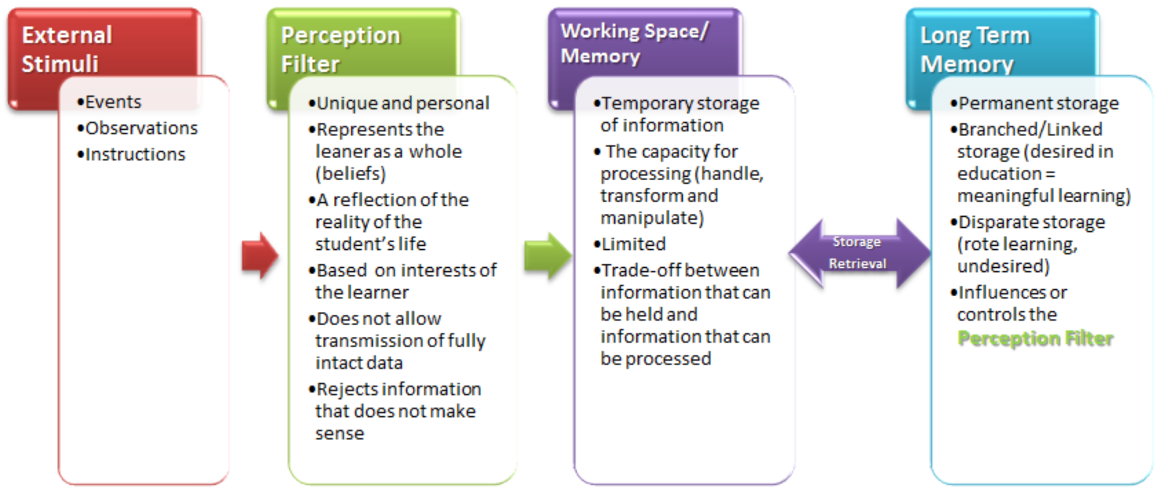

Figure 4. Information Processing Model (Johnstone, 1997; 2010) annotated by the researcher.

The Information Processing Model deals with "patterns of human thinking that are universal" (Johnstone, 1997, p. 268). In modelling such patterns, the limitations of the learners' cognitive abilities become clear. Johnstone and El-Banna (1986) found that working memory capacity was a significant factor in determining examination and test performance. The notion of cognitive architecture is strongly linked to the model: Sweller, van Merrienboer and Paas (1998, pp. 252-256) describe cognitive architecture as the working memory and long term memory and the processes of schema construction and automation, which link the two. Thus, the cognitive architecture of the student must be taken into account for effective instructional material design and delivery (Sweller, et al., 1998).

The following statement by Reid (2009, p. 135) and the implications thereof will be used to close this section on the Information Processing Model: "If working memory is the place where thinking, understanding and problem-solving take place, then it is the place where evaluations occur and beliefs and attitudes form."

2.3.2 COGNITIVE LOAD THEORY

To begin to develop an understanding of Cognitive Load Theory (CLT), this section begins with a quote from Sweller (1994, p. 310), "Our limited processing capacity is one of the most important and well known of our cognitive characteristics". CLT seeks to understand the general factors influencing cognitive processing capacity in humans.

It has been found that only a finite amount of information can be processed successfully by an individual at a given time (Miller, 1956; Johnstone and El-Banna 1986, 1989). Too much information to receive, process, and remember causes an information bottle-neck effect or what is now known as an overload (Miller, 1956, p. 95). Miller (1956) describes chunks of information as the grouping or organising of bits of information into schemas. A chunk of information can be expanded or recoded to incorporate familiar bits of information or smaller chunks, as the person learns and becomes familiar with the information (Miller, 1956, p. 93; Sweller, 1994, p. 306). Once a chunk has been formed and stored within the long-term memory it is retrieved as a whole or one unit, regardless of the complexity of the chunk. This has certain implications on learning: what is perceived as a single chunk of information to an expert may be viewed as several chunks to a novice and as such will be processed with more difficulty.

The working memory is a theoretical space in the mind where information is processed before the possibility of storage in the long-term memory (see Section 2.3.1). CLT seeks to understand the factors which influence the availability of working memory. Sweller (1994, p.307) proposed that cognitive load has at least two components, the intrinsic load and the extraneous load. The intrinsic load is unique to the learning materials and the elemental interactivity, that is, it is fixed regardless of "instructional manipulations" (Paas, Renkl and Sweller, 2003, p. 1). In other words, the intrinsic load is specific to the topic at hand: for example the unfamiliarity, inherent complexity and difficulty.

The extraneous cognitive load or ineffective cognitive load, hinders schema acquisition and automation (Paas et al., 2003, p. 2). Extraneous cognitive load is viewed as artificial because it arises from the instructional methods used (Sweller, 1994). Seery (2012, p. 25) explains that "poor materials or those that require a large amount of working memory to process will increase the (cognitive) load and leave little capacity for learning".

In later literature, a third component of cognitive load has been proposed, that is the germane cognitive load. Paas et al. (2003) refers to this load as being effective as it increases the extent of learning. Germane load represents the cognitive processes enabling the acquisition and automation of schema or linked chunks of information; this is particularly important for problem solving. Seery (2012) states that the amount of processing ability remaining for germane load represents the remainder after intrinsic and extraneous load have been taken into account. Fig. 5 below shows the three additive components of cognitive load.

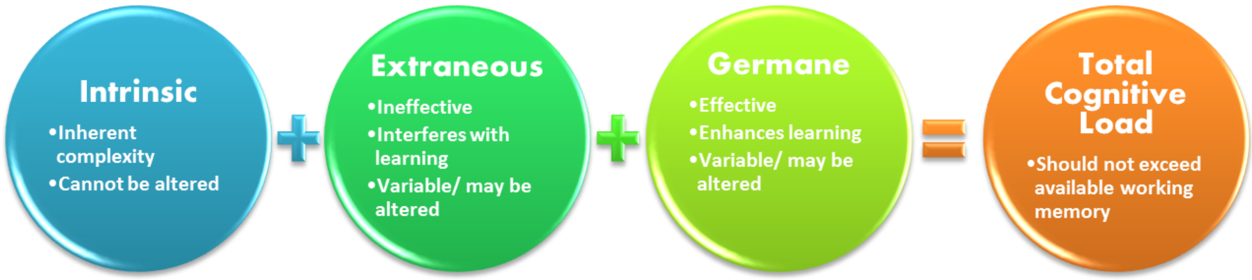

Figure 5. A representation of Cognitive Load, adapted from Seery (2012) and annotated by referring to Pass et al. (2003).

The implications of CLT for teaching and learning are that instructors should be aware of, and minimize, extraneous load: "Often teachers do not 'hear' the 'noise' because they have long since got used to it, but for first-time learners, the problem is acute" (Johnstone and El-Banna, 1989, p. 167).

Learning activities of which the structure does not take into account the cognitive architecture of the learner will not be effective. Cognitive load theory has implications on how instruction and instructional materials are designed: "Learning will be difficult if cognitive load is high, irrespective of its source" (Sweller, 1994, p. 308).

2.3.3 PRE-LECTURES

A pre-lecture is defined as "any activity a student might do in preparation for your lecture" (Seery, 2010, p. 1). Pre-lectures do not have a set format and can take many forms, for example, prescribed reading, a video or a worksheet (Sirhan, Gray, Johnstone and Reid, 1999).

The intent of a pre-lecture is to minimise the cognitive load on a learner by introducing new information to the learner before formal teaching takes place. The main idea behind the pre-lecture is that the new information is encountered in advance and is thus familiar by the time it is re-addressed or built-on by the educator (Seery, 2012). To refer back to Cognitive Load Theory, the aim of a pre-lecture is to minimise the intrinsic load component.

Additionally, unnecessary extraneous load should be actively reduced by the instructor in pre-lecture design. Seery (2012) cautions that any pre-lecture material should be succinct: concepts should be clear with no distractors or noise. Pre-lectures themselves should not be time consuming; they serve merely as an introduction.

Pre-lectures are beneficial to students as they are a tool which deliberately minimises cognitive load and thus expands the students' processing capacity during class time. This has bearings on the pace and the quality of teaching in the classroom. For example, time will not be spent on introducing new concepts, but the application of such may be discussed in greater detail. The statement by Seery and Donnelly (2011, p. 3) is particularly relevant to the student sample group within this study, "learners without prior knowledge must use a significant proportion of the limited working memory capacity in accommodating new terminology and concepts, whereas learners with prior knowledge can progress to linking new information with existing knowledge."

2.3.4 CHEMORGANISERS

In 1998 and 1999 the Chemorganiser was created for a first year general chemistry course by two colleagues, Ghassan Sirhan from Palestine and Norman Reid from Scotland (Reid and Sirhan, 2001). As the name “Chemorganiser” implies, it is a structured framework (which fits onto an A4 page) that deals with a single topic in the chemistry syllabus (Reid and Sirhan, 2002). Approximately 60 Chemorganisers were designed and these simplified constructs take students from a problem statement into a strategy, a solution and finally a summary and self-assessment questions; whilst providing other useful pieces of information under the section “Concepts”. The basic outline can be seen below, Fig. 6.

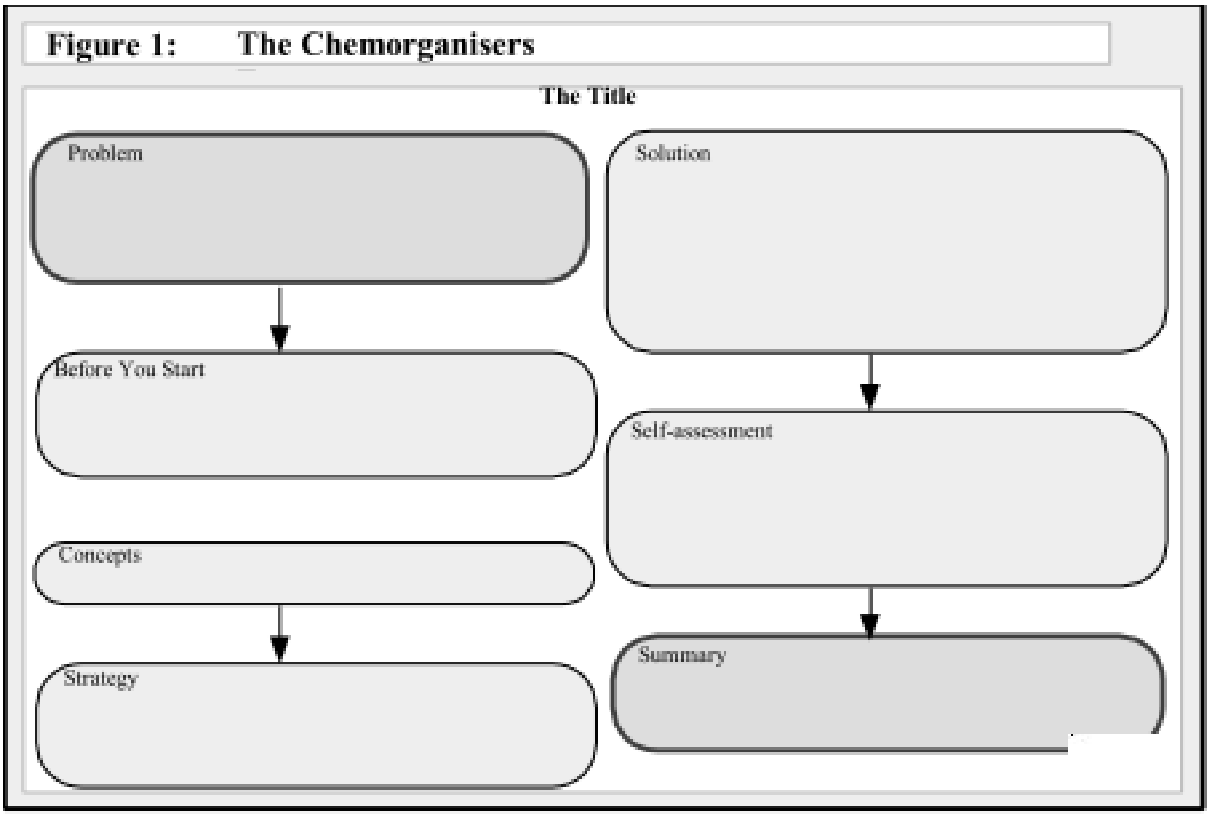

Figure 6. The format of a Chemorganiser, taken from Reid and Sirhan (2002, p. 54).

There is a trail of theoretical frameworks used in the design of the Chemorganiser: Ausubel’s (1968) notion of the psychology of learning was the starting block for the concept of the Chemorganiser. To briefly expand on the ideas held by Ausubel (1968), the instructor needs to be aware of what the student knows, thinks s/he knows or does not know and build on the knowledge from there. The students’ existing knowledge base and their own characteristics and beliefs create a filter which influences the uptake and storage of new information, thus the conundrum that information can seldom be transferred intact from instructor to learner (Johnstone, 2010, p. 23; Bodner et al. 2001).

Cracolice (2005, p. 16) presents a neat summary of Ausubel's work with the statement that "learning occurs through the modification of existing knowledge".

Chemorganisers were designed with the aim to reduce the Cognitive Load by mimicking the action of a pre-lecture. Chemorganisers were not designed to replace traditional teaching, but as an unthreatening aid which students could use in cooperative learning, if they so wished (Reid and Sirhan, 2001). Seery (2012, p. 24), views this as a low-risk strategy for all concerned, as students will not lose out on any of the content in the syllabus if they do not make use of the Chemorganisers.

Chemorganisers were designed to be visually elegant materials, chunking concepts for students. The demand on the working memory is lessened by reducing the extrinsic load and freeing processing and schema acquisition ability (germane cognitive load) and as such information is more easily processed (Chandler and Sweller, 1991).

2.3.5 IMPLEMENTATION OF THE CHEMORGANISERS

Chemorganisers were implemented in two ways: at the beginning of the course Chemorganisers dealing with mathematical skills were given to students by the lecturers. Students were encouraged to read the Chemorganiser, discuss it as a class with the instructor, use it to complete selected problems and continue to use it throughout the course (Sirhan and Reid, 2001). Chemorganisers dealing with specific chemistry topics were made available before each block of relevant lectures. These were not explained or discussed, but made freely available.

The researcher entered into correspondence with Prof Norman Reid, to discover why the mode of implementation changed. It was revealed that the buy-in from other lecturers on the course was not always high with regards to the Chemorganisers; therefore Chemorganisers were offered in a subtle way to students, which did not require active implementation.

The researcher aims to implement the Chemorganisers in the first way described: using a detailed discussion of the Chemorganiser with the students before they use it to solve problems on their own. Prof Norman Reid confirmed that this is the preferred mode of implementation and supports the use of the Chemorganiser in such a way.

2.4 THEORECTICAL COMPARISON OF INTERVENTION APPROACHES

It is possible to see important differences when these two teaching styles lie in contrast to one another and it is for this reason that exploring these two, previously successful methods holds so much promise within the context of this study. Table 2 below contrasts the approaches, now called interventions in keeping with the quasi-experimental nature of this study.

Table 2. Comparison of POGIL and the Chemorganiser.

Point of Comparison	POGIL	Chemorganiser
1. Region	United Sates of America	Scotland
2. Theoretical Framework	The Learning Cycle	Cognitive Load theory
3. Instructor and Student Roles	Student-centred	Traditional or teacher-centred
4. Resource material	Information-rich worksheets with many opportunities for students to form ideas	Summary in which ideas are linked and stepwise procedures are given
5. Optimal Facilities	Preferably flat floor classroom with loose tables	An ordinary classroom with no specific requirements
6. Target Population	All students should benefit	"Weak" students or poor performers, with limited chemistry background knowledge, should benefit the most.

2.4.1 DISCUSSION OF THE POINTS OF COMPARISON

1. Region

The two interventions both originated in first world settings but they were influenced by different contextual settings, such as: the history, politics, economics and educational paradigms of the region.

2. Theoretical Framework

Two theoretical frameworks underpin the two educational interventions. Both frameworks aim to present an understanding of the processes behind how students learn. The Learning Cycle, in which students explore, conceive and apply concepts, is the back bone of the POGIL approach; that is, students construct their own knowledge together. There are foreseen implications on knowledge ownership and student confidence when comparing the two proposed interventions. Chemorganisers were developed based on the principles of Cognitive Load theory, in which instructors are mindful of the constraints of the working memory and as such seek to develop resources which do not flood the working memory but aid the assimilation of new knowledge.

3. Instructor and Student Roles

The role of the instructor within the classroom lies on opposite sides of the spectrum when comparing POGIL and the Chemorganiser. The POGIL approach is student-centred, removing the instructor from the traditional role of classroom management, time keeping and imparting knowledge, to a side-line position of subtly shepherding the class. Such a change will increase the level of demand on the students. In a Chemorganiser classroom, the lesson structure and the role of the instructor remains largely unaltered when compared to the original way in which the tutorials are structured. The scaffolding supplied by the Chemorganisers should decrease the demand level on students.

4. Resource material

When comparing the structure of resource, physical differences are immediately visible: Chemorganisers consist of only one A4 page per topic within a theme, whereas the POGIL approach employs comparatively lengthy worksheets which originally came from a workbook. The Chemorganiser re-explains complex terminology whereas the POGIL worksheets require a higher level of language abilities in general. The physical nature of the resources has deliberate implications on the level of detail supplied and the type of information presented in keeping with the theoretical frameworks from which they were born.

5. Optimal Facilities

In order for POGIL to work as described in literature, the venue should be able to accommodate group-work. For example, free-standing tables and chairs where students can collaborate in their groups. Thus, the nature of the facilities available will influence the ease of implementation of POGIL. Chemorganisers have no defined social structure and therefore no optimal arrangement of facilities: students work individually and confer with their peers when and if they feel the need to do so.

6. Target Population

Neither approach has been reported to disadvantage students, otherwise it would not have been eligible for this this study. POGIL is seen to benefit all students in terms of performance and professionalism, whereas, the Chemorganiser approach has been documented to close the performance gap between strong and weaker students; without any disadvantage to strong students.

It is expected that the reader will have already gleaned the differences between the approaches through the preceding literature review. It is the opinion of the researcher that by starkly contrasting the interventions, the study will be mindful of the challenges of implementing such complex and different approaches. Furthermore, the differences between the interventions cannot be controlled for, or manipulated, within the study and as such should be mentioned as variables beyond the control of the researcher.

2.5 THROUGH THE LOOKING GLASS

It is clear from Section 2.4 that the proposed interventions are substantially different from each other in many ways. In order to fairly evaluate both interventions, a robust theoretical framework must be selected which includes meaningful variables, for both this study and within an educational context. For this reason, a brief history on the attempts to evaluate school and instructional effectiveness is described, followed by the selection of a model which is respected in educational fields for evaluating effectiveness. The researcher argues that such a model is as valid for schooling as it is for the foundational level of tertiary education and, as such, will be used in this study.

2.5.1 HISTORY OF MODELLING TEACHING AND LEARNING EFFICIENCY

Initial models, proposed from 1970s to 1990s, for evaluating "school effectiveness" were based on educational product functions, that is, the use of mathematical expressions or equations based on economics relating to the school (Scheerens, 1997, p. 270). The underlying assumption of such models is that increased input will lead to advances in the schooling outputs. In simpler terms, education at a school was seen as a product of the resources put into the school, such as pupil/teacher ratio, teacher salary and overall measures of per pupil expenditure (Scheerens, 1997, p. 270, citing Hanushek, 1986). Scheerens (1990, p. 62) mentions that social indicators of education were also used in the past, for example, characteristics of the population were important to give a context of the school and predict schooling outcomes.

The data, both economic and social, are considered by Scheerens (1990, pp. 62-63) as macro-level data, over which the schools themselves have little or no influence. There was a shift to begin to look at micro-level data or "manipulative input factors" at the class room level. Scheerens and Creemers (1989, p. 691) explain that due to this shift there was a divide in what was considered "school effectiveness" versus "instructional effectiveness". In the next section, Section 2.5.2, the Integrated Model of School Effectiveness is explained as a model which takes into account both school and instructional effectiveness, creating a multilevel perspective on education and student achievement.

Carroll (1963, 1989) was considered a pioneer in proposing a causal model for instructional effectiveness and as such has been built upon by researchers over time. The essence of the quasi-mathematical model is that learning is a function of both the learners' and teacher's efforts in relation to effort **required** from the learner. The model includes five classroom level variables which influence learning and student achievement: aptitude, opportunity to learn (in terms of a sufficient amount of time allocated for a learning task), perseverance on the behalf of the student, the quality of the instruction and finally, the student's ability to understand the instruction given. Carroll (1989) states that the model assumes that students differ in the amount of learning time they need and points out the challenges this may pose in classroom management. Reeves (2011, p. 9; 1997, p.1) makes a neat diagrammatic summary of the model as follows in Fig. 7.

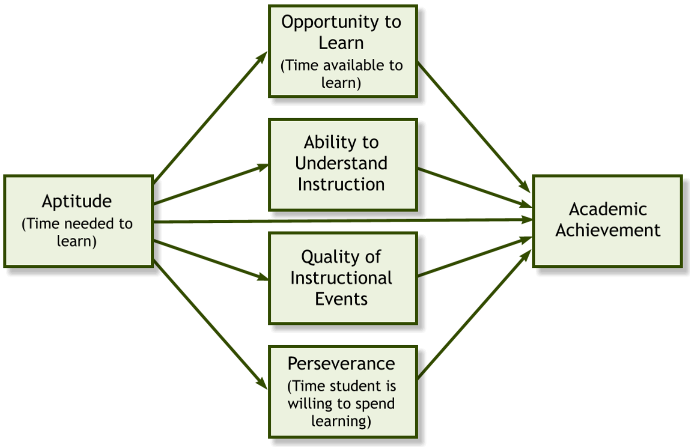

Figure 7. Carroll's Model of School Learning (1963).

Carroll (1989, p. 29) admits that the variable, "quality of instruction", was difficult to measure and define despite its prominent place in the model, because the model "does not deal extensively with elements involved in quality of instruction". Creemers (1994; 1999) sought to expand the notion of quality of instruction into three main aspects: **curriculum** (or textbook followed), **grouping procedures** (to group or organise students to suit the educational method and its outcomes) and **teacher behaviour** (management, clarity of presentation, evaluation, feedback and corrective instruction) (Creemers, 1999, p. 6).

Instructional effectiveness remains a complex construct, with many variables both to measure and to understand (Campbell, Kyriakidis, Muijs and Robison, 2005, p. 217). Recently, Tinto (2012, p. 4) promoted criteria to improve effectiveness at the classroom or instructional level, "(high) expectations, support, assessment and feedback, and involvement".

With the dawn of the paradigm of constructivism, late in the history of school and instructional effectiveness, a new variable has arisen: The ability of the learner to play an "active role" in their learning or education (Scheerens, 2004, p. 31; Scheerens, 1997, p. 297). Scheerens (2004, p. 31) describes learning in lieu of this as "self-regulated with lots of opportunity for discovery and students' own interpretation of events". A distinction lies between older models in which the learner was considered passive in the learning process, to newer models where the potential of active student learning is often taken into consideration, where and however possible.

2.5.2 INTEGRATED MODEL OF SCHOOL EFFECTIVENESS

More recently, there has been a drive to blend findings of school effectiveness research and instructional research to create multi-level dynamic models which propose complex causal links in an educational context, indicating overall effectiveness (Scheerens, 1997, p. 280). Such a model, as first proposed by Scheerens (1990), is the Integrated Model of School Effectiveness. Within such a model, process indicators that are "positively associated with educational achievement" are portrayed (Scheerens, 1990, p. 61). Scheerens (1990, p. 64) explains process indicators as: "characteristics of educational systems that can be manipulated" and the outputs of such manipulations are measurable, usually in terms of student achievement.

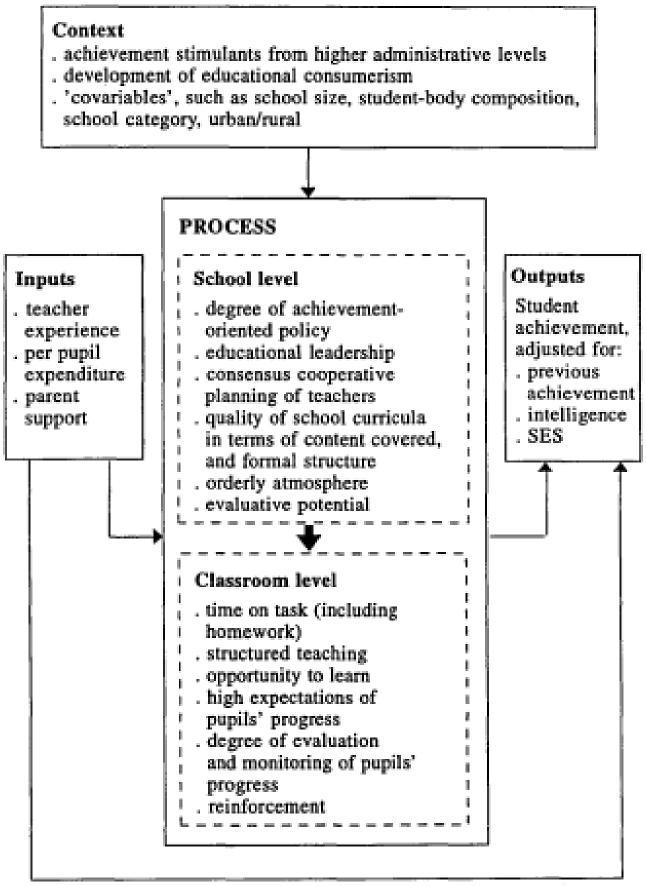

Figure 8. Integrated model of school effectiveness (Scheerens, 1990, p. 73).

Such process indicators, or characteristics, fall into different categories as seen in Fig. 8. Scheerens (1990, p. 72) sought to represent "pupil-, classroom-, school and environmental characteristics" in his model; whilst working within the basic accepted framework of input, process and output (student achievement). An undertaking of this magnitude has led to a multi-dimensional model which is relevant to multiple applications, whether it is at the governmental policy making level, official/district level, school managerial level or in the classroom by an educator (Scheerens, 1990, p. 75). The inter-changeability of the applications of the Integrated Model of School Effectiveness, from macro, meso to micro (Scheerens, 1990 p. 78) and the ability to focus on specific indicators at specific levels makes such a model suitable for a study in tertiary education, where not all of the variables are relevant or open to manipulation.

Wide use of and re-interpretations of the model have led to a significant knowledge basis on the effectiveness of education in various settings and the applicability of the model. In his review, Scheerens (2004) notes a difference in the relevance of the process indicators based on whether the school is in a financially constrained, developing environment or not. In the case of underprivileged schools in developing regions, the impact of the inaccessibility and unavailability of resources is the most influential on the schools' overall effectiveness. Schools in a more fortunate socio-economic context are similar in that processes at the classroom level are the most influential in terms of student achievement. The context of this study is assumed to be the latter, in which classroom level variables will influence the overall effectiveness.

After summarising various studies, Scheerens (2004, pp. 49-50), isolated three key dimensions most important in enhancing effectiveness. These three dimensions of **relevance, time** and **structure**; encapsulate the given ***process indicators*** of the Integrated Model of School Effectiveness within themselves. Such dimensions, as explained forthwith, can be seen as the current climax and refinement of the model.

Table 3. Critical dimensions of Effectiveness

Structure • ***Structured teaching*** • Teaching "technology" • Stimulating engagement • Monitoring and Questioning	How the teaching is structured depends on the route the educator choses to employ. Teaching technology refers to the use of materials and teaching methods relevant to the students' characteristics, that is, the amount of scaffolding given to the student is relevant.
Relevance • ***Opportunity to learn*** • Curriculum alignment	The learning materials chosen or the subject matter used should meet the required objectives of the curriculum. Any activities used should prepare the student for assessment.

Time • *Time on task*	This is the time spent directly on learning activities, both inside and outside of the classroom. Time spent on organising the classroom and other distractions limit the time on task or productive time usage.

2.5.3 CONCEPTUAL FRAMEWORK OF THE STUDY

A conceptual framework acts as the link between the existing knowledge presented in the literature review, the methodology and the findings of a study. That is, a conceptual framework provides the researcher with a lens through which the findings of the study can be interpreted. Teddlie and Tashakkori (2009, p. 89) assert that building a conceptual framework is often highly inductive in that researchers may use current research literature and theories in combination with the researcher's own intuition.

The conceptual framework of this study is largely based on the Integrated Model of School Effectiveness and its refinements, namely the critical dimensions of structure, relevance and time. Opportunity to learn, time, the addition of student preference and finally the output of student performance form the four pillars of the conceptual framework. Each of these constructs has led to a secondary research question, which in combination will provide insight to answer the primary research question regarding the overall effectiveness of POGIL and the Chemorganiser in the context of foundation chemistry.

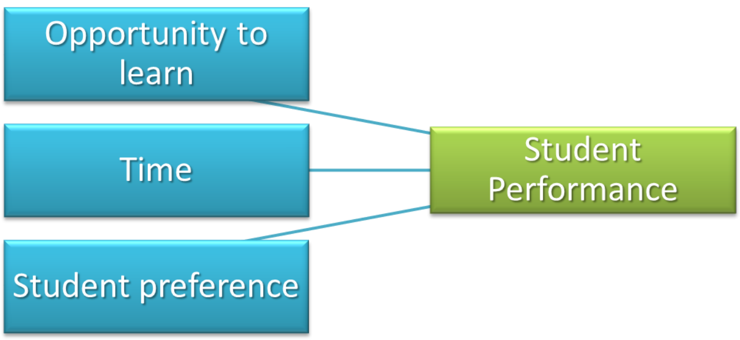

Figure 9. Outline of the conceptual framework used to explore effectiveness.

In Table 3 the dimension of **structure** is broken down into four variables, one of which (structured teaching) was an original process indicator from the Integrated Model of School Effectiveness. The researcher asserts that the two interventions, POGIL and the Chemorganiser, differ in terms of all four variables. Firstly, the decision of the researcher to employ two different interventions immediately implies that the routes of **structured teaching** will be different. **Teaching technology** differs for both interventions: the Chemorganiser is a highly scaffolded learning aid whereas POGIL offers structure in terms of guiding questions. The third variable **stimulating engagement** also differs for each: Chemorganisers mainly stimulate the students to engage with the tool on an individual basis, whereas POGIL requires social engagement. The final variable is **monitoring and questioning**. Chemorganiser students should be able to monitor their own progress and understanding through a comparison of their work to that of the explained worked example. "Monitoring and questioning" is more complex in a group as this is generally achieved socially or externally. Thus the various differences in the structure of each intervention has led to the formation of the primary research question, *How effective are each of the two educational approaches, POGIL and the Chemorganiser, in the context of foundation chemistry?*

Relevance is the first dimension to be explored in this study. **Curriculum alignment** is ensured as both sets of intervention materials used in this study were aligned with the course outcomes from the onset. Thus this variable is not examinable. Therefore, the process indicator of **opportunity to learn** will be the proxy for the dimension of relevance within this study as given in Fig. 10. The variable of opportunity to learn will consist of two parts, firstly student opinions of *preparedness for assessment* which will highlight student confidence in the intervention. The second component of opportunity to learn, *student involvement*, is a construct created by the researcher which incorporates and expands upon the idea of perseverance proposed by Carroll (Fig. 7), in line with the objective of having active (not passive) learners. At tertiary level students are responsible (at least in part) for their own education, making this variable more substantial than it would be at school: student involvement in terms of engagement is readily noted and levels of attendance are easily surmised.

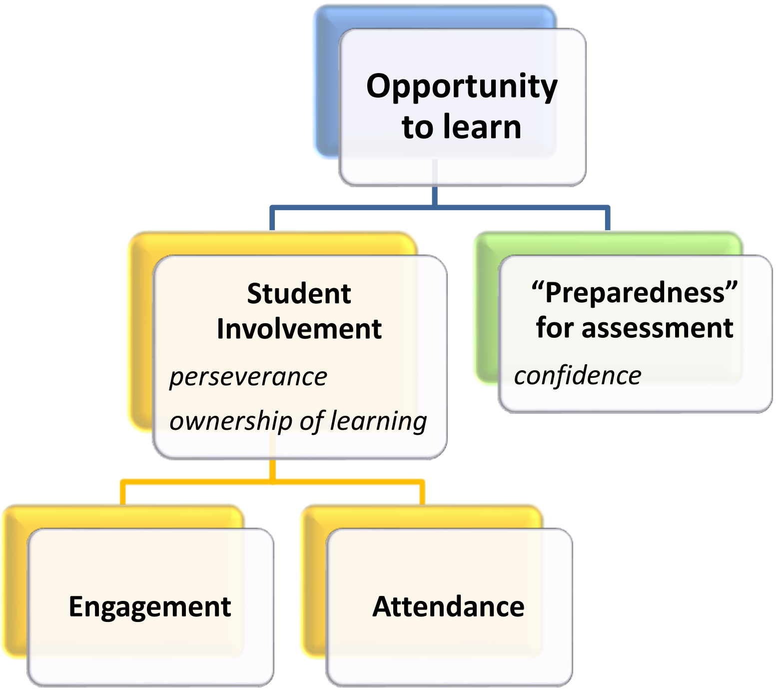

Figure 10. A representation of the researcher's construct of the variable "Opportunity to learn" within the study.

The dimension of relevance in the conceptual framework lead to the formulation of the secondary research question: *What are the impacts on the students' opportunity to learn within each approach?*

The next variable within the framework is aligned with Scheerens' (2004) dimension of **time**. Investigations will be made into the variable **time on task**; that is the amount of time used productively and unproductively within the classroom environment. Students' experience of homework and time required for studying during the intervention will also be considered. The following research secondary question was developed to examine the dimension of time within the study: *What influence does each approach have on productivity, both inside and outside the classroom?*

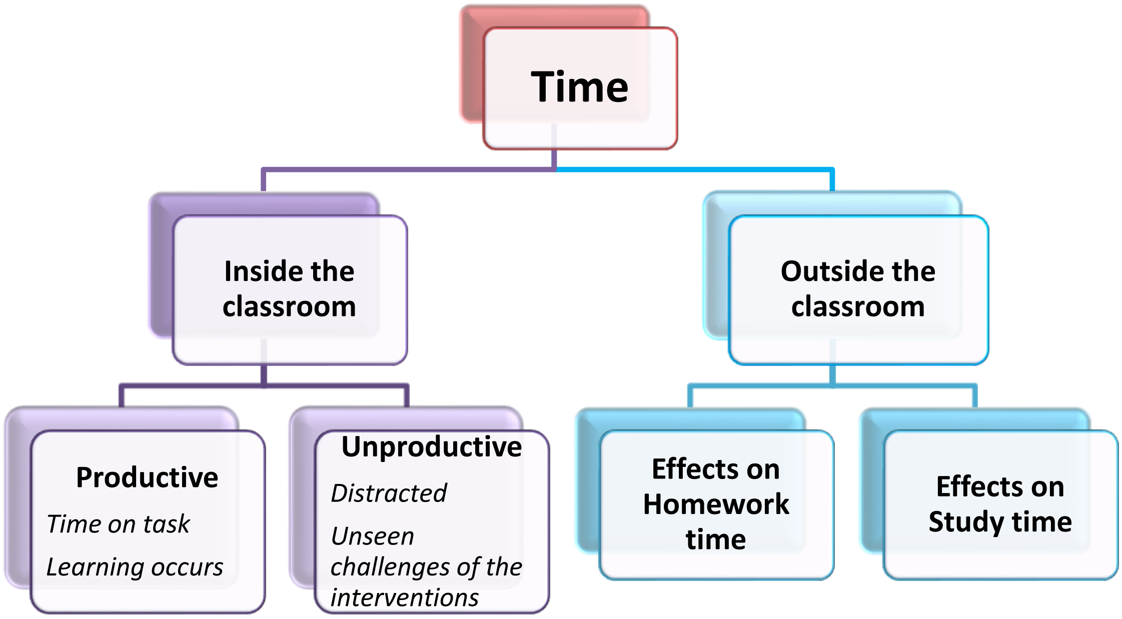

Figure 11. A representation of the researcher's construct of the variable "Time" within the study.

It is the opinion of the researcher that student happiness, preference and attitude is a factor which underlies educational effectiveness (although it may not be explicitly stated within literary models). The affective response of the student will influence behaviour in terms of engagement and motivation. Thus **student preference** was introduced as a theoretical construct within the conceptual framework, leading to the third secondary research question: *How are the approaches received by the students?*

The output of the Integrated Model of School Effectiveness is adjusted student achievement (Fig. 8). As such, **student performance** or **achievement** represents the final construct of the conceptual framework of this study. A control will be present in both years of the study to provide an "adjusted" perspective of the intervention groups' achievements. Student performance may be the most straight forward construct to measure within the study; the collection and processing of student grades to answer the research question: *How do the approaches influence student performance?* However, student performance relies upon the other three constructs of **opportunity to learn**, **time** and **student preference**, to be fully appreciated.

2.6 SYNTHESIS

Each of the interventions was unpacked in terms of related and founding educational theories. Social constructivism, in which students develop an understanding of concepts together, was linked to group work. Group work is as essential in a POGIL environment as the guided-inquiry worksheets, which are aligned with the Learning Cycle as groups of students are exposed to, discover end apply new concepts. This type of learning is expected to hold deeper meaning and the inclusion of rotating roles promote the growth of professional skills.

The cognitive construct of the working memory or working space was pivotal to the development of the Chemorganisers. Working memory is the region described within the Information Processing Model where information is temporarily stored and processed before it may be transferred to long-term memory. Processing ability of the working memory is effected by the three components of Cognitive Load that is the intrinsic, extraneous and germane loads. Chemorganisers are purposefully designed to limit the cognitive load.

The implementation of both the POGIL and Chemorganiser instructional approaches was discussed in this chapter and it concluded with a review of measures of school, and later instructional, effectiveness. The Integrated Model of School Effectiveness was chosen as the backbone of the conceptual framework of this study which focused specifically on student performance, productivity, opportunity to learn and student preference to gain a holistic view of effectiveness (linked to the research questions in Section 1.7). Such variables dictated the wide variety of data collection strategies and analyses described in Chapter 3.

CHAPTER 3: RESEARCH DESIGN AND METHOLODY

3.1 INTRODUCTION

This chapter begins with research premises which portray the personal and philosophical background of the study. Next, the mode of inquiry specific to this study is presented, resulting in the ultimate design of the research. After sampling and other practicalities regarding the study are discussed, the chosen data collection methods and the proposed means of analysis are presented. The third chapter concludes with the limitations of this study along with the numerous ethical considerations for such a study.

3.2 RESEARCH PARADIGM

The audience of this study is most likely split in two: members of science faculties are often post-positivists (or positivist) and may dismiss qualitative findings or even feel that they jeopardise the integrity of the study (Giddings, 2006; Makay, 2010). On the other hand educational practitioners often favour rich descriptive studies which do not include any intervention as experimentation may benefit or disadvantage the sample or change the situation.

Accepted or preferred paradigms have changed throughout recent history and even the encompassment of a research paradigm is still debated: is it a general world view or a set of beliefs held by a research community (Morgan, 2007)? For the purpose of this study, the definition given by Giddings and Grant (2006, p. 4) will be used

> *"A researcher's paradigm reflects their beliefs about what reality is (ontology), what counts as knowledge (epistemology), how one gains knowledge (methodology), and the values one holds (axiology)."*

In order to answer the complex research questions proposed in this study, a pragmatic approach was taken so that an interactive relationship can be appreciated between objectivity and subjective interpretations (Teddlie and Tashakkori, 2009, p. 89). The term "intersubjectivity" was advocated by Morgan (2007, p. 71) to emphasise that there is a back and forth relationship between the subjective and the objective in all research. Hall (2007) asserts that pragmatism is a-paradigmatic and even Morgan (2007) who proposed the shift towards pragmatism, preferred to view it as an "approach" and not strictly as a paradigm. Be that as it may, pragmatism is a stance that searches for a middle ground between traditional dualisms like positivism and constructivism (Johnson and Onwuegbuzie, 2004).

The key motivation of pragmatism is to find the ultimate truth of a situation, irrespective of the means taken to arrive there, but at the same time acknowledging that any conclusions made are ultimately tentative (Johnson and Onwuegbuzie, 2004). Pragmatism is value driven: how a topic is researched will be congruent with the researcher's value system (Teddlie and Tashakkori, 2009). From a pragmatic approach, the decision to be mindful and inclusive of values such as democracy, freedom, equality, and progress within the research process is necessary (Johnson and Onwuegbuzie, 2004). Indeed, research within the South African context should always be mindful of these community-based values.

In summary, the statements of Teddlie and Tashakkori (2009, p. 86) best describe pragmatism as it is considered within this study, "the two major characteristics of pragmatism are the rejection of the dogmatic either-or choice between constructivism and postpositivism and the search for practical answers to questions that intrigue the investigator".

3.3 METHODOLOGICAL APPROACH

When choosing a methodology, Devetak, Glažar and Vogrinc (2009, p. 83) maintain the chosen methodology should provide a path which leads the researcher "easily, swiftly and most efficiently to the most reliable findings that adequately answer the research questions". Case and Light (2011, p. 205) define methodology not only as the choice of data collection methods but as a "theoretical justification for the use of these methods and the kinds of knowledge that they are able to generate". The priority of this study is to gain a holistic understanding of each educational intervention within our specific context.

Due to the complex nature of the research questions in this study, a mixed methods approach was selected. It is accepted that mixed methods research represents the use of both quantitative and qualitative data collection and analysis within a study (Creswell and Plano Clark, 2011; McMillan and Schumaker, 2010).

The main benefit of mixed methods designs is that the study should accent the strengths of quantitative and qualitative research methods, so that the impact of the research is greater than the sum of the quantitative and qualitative origins. Johnson and Onwuegbuzie (2004, p. 14) make the bold claim that the use of mixed methods often results in superior research as the best and most appropriate data collection methods may be selected and used in combination (eclecticism) without the restrictive exclusivity of either quantitative or qualitative methodologies.

A potential shortcoming in the choice of a mixed methods design is that the researcher may not have identical skill levels in both quantitative and qualitative research methods (Northern Illinois

University, 2013). It is the undertaking of the researcher to use the chosen methods to the best of her ability by educating myself comprehensively in both methods.

3.4 OVERVIEW OF THE STUDY

Before delving into the technical details of the chosen research design, a synopsis of the study and the general motivations behind the structure of the study will be presented in this section. To begin with, the overall aim of this study is to explore the effectiveness through strengths and weaknesses of POGIL and the Chemorganisers within a South African tertiary education setting. Four secondary research questions were formulated to explore the attributes of each intervention (as presented in Section 1.7 and justified in Section 2.5.3).

- How do the approaches influence student performance?
- What are the impacts on the students' opportunity to learn within each approach?
- What influence does each approach have on productivity, both inside and outside the classroom?
- How are the approaches received by the students?

By appraising these questions, it can be seen that the type of data that should be collected does not qualify as either quantitative or qualitative but as a mixture of both relating to each question. That is, the first research question can be answered based solely with quantitative data, whereas a combination of qualitative and quantitative data will provide a richer description of the impact of the interventions as probed by the remaining three questions. Thus, a mixed methods approach was chosen for this study.

A variety of data collection methods were chosen for this study including observations, test scores, focus group interviews and questionnaires (as will be discussed fully in section 3.12). The nature of the research questions influenced when the data collection took place: for example, observations were on-going throughout the course of the interventions, test scores were collected at the immediate culmination of the interventions coinciding with batches of focus group interviews. A brief analysis of the findings from the focus group interviews and observations resulted in the formation of a questionnaire which was administered as the final mode of data collection in a given year of the study. Thus, the sequencing of qualitative and quantitative strands in this study may be viewed as intertwined, it is for this reason that a concurrent research design was chosen (see the subsequent Section 3.5).

In returning to the main objective of this study - to explore two educational interventions - it follows that at least two experimental groups must be used in the course of the study. In a given year of the study two experimental groups were utilised and an intervention was allocated to each group. Such an arrangement allows for the control of variables within the study, for example both experimental groups undergo the interventions at the same time (see Section 3.9) during the same chemistry themes (see Section 3.8). Therefore no bias will be introduced into the study by student fatigue during the course of the semester or by the inherent and unique difficulties encountered in different topics in the chemistry syllabus. The motivation behind this arrangement is to keep the study as scientifically rigorous as possible.

Two themes, ***mole concept and stoichiometry*** and ***redox reactions*** were eligible for intervention in this study based on the resources available and their alignment with the curriculum. It was decided that exposure over both themes will allow students to grow in proficiency and mastery of the allocated intervention and as such yield more valid findings in terms of student performance and student attitude. Such exposure will allow meaningful analysis of any findings from a longitudinal or "length of study" perspective, adding another layer to the study over time.

Finally, it was decided that the study should be repeated over two years, with two new experimental groups in the second year. The themes for instruction, ***mole concept and stoichiometry*** and ***redox reactions,*** remaining the same. There are many motivations for this decision, firstly, in order for the results of this study to be respected professionally, the results need to be reproducible not anomalous, thus one implementation of each intervention does not suffice. Secondly, the researcher (who is also the instructor) will gain proficiency in the interventions from one year to the next, thus improving the quality of the delivery of the interventions and as such the quality of the findings of the study.

3.5 RESEARCH DESIGN

Concurrent mixed methods designs are also referred to as parallel mixed methods designs (Teddlie and Tashakkori, 2009). As the name implies, both quantitative and qualitative strands are worked with and the combination of these is planned to answer research questions. Creswell (2014) explained that the integration of quantitative and qualitative data can be done in three ways: to merge the data, to connect or build the data or to embed the data. The intention behind merging different databases is to create a more complete understanding of the problem underpinning the study. This design may also be seen as the "Triangulation Mixed Methods Design" (Swanson and Holton, 2005, p. 230) where data is merged to make comparisons between the "detailed contextualized qualitative data and the more normative quantitative data"; triangulation adds validity to the findings of this study yet Creswell (2014) posited that the use of such a term may be out-dated.

The basic design of the study is concurrent in that quantitative data is collected at the same time as qualitative data; however, a slight time lapse may occur (Creswell and Plano Clark, 2011). As the study is quasi-experimental in nature, the basic concurrent design was the device used to gather data during and after the implementation of the educational interventions. Figure 12 below shows Creswell's concurrent design overlaid on the experimental interventions. This basic research design was followed in the first year and again in the second year of the study. Creswell, Shope, Plano Clark and Green (2006, p. 1) have surmised that in some cases mixed methods studies "relegates qualitative research to secondary or auxiliary status", therefore no priority was given to either the qualitative or the quantitative strands as a holistic and unbiased viewpoint is essential.

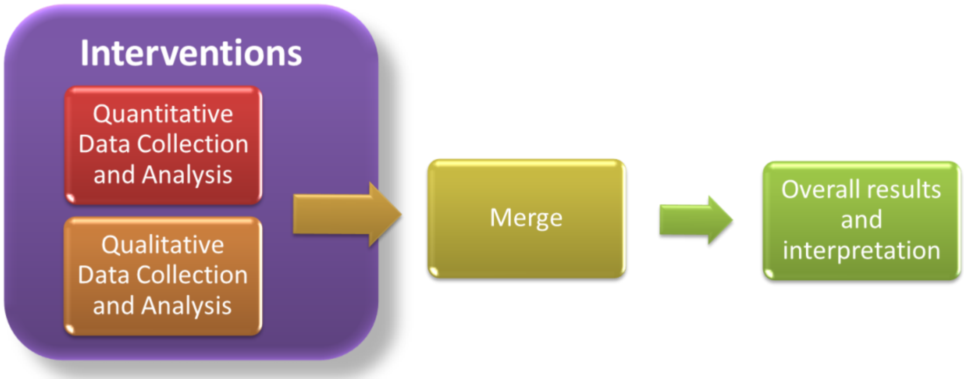

Figure 12. Diagrammatic representation of the concurrent research design of this study.

3.6 DESCRIPTION OF COURSE STRUCTURE

On a weekly basis within the chemistry module, students attend a two-hour lecture in a class of approximately 200 students as well as three one-hour tutorial sessions, in smaller groups of approximately 50 students. The lecture and tutorial groups are fixed; students may not change groups at random. The grouping of students is done by the campus director and is not unique to chemistry. Students also participate in a three-hour laboratory practical only every second week seeing that a weekly practical is not deemed necessary in a prolonged programme. All students have the **same** chemistry lecturer but once divided into tutorial groups, the students are assigned to one of three tutorial instructors. There are nine tutorial groups divided between the three instructors. Each instructor is unique in terms of personal teaching style. Tutorial sessions are guided attentively by the instructor, and it is within this environment that students grapple with prescribed problems. The greatest impact can be made on students' learning during the tutorial sessions, and for this reason the tutorial sessions present the ideal opportunity for meaningful interventions within this study.

3.7 ASSESSMENT STRUCTURE OF THE COURSE

Student grades within the course consist of an equal weighting between the semester mark and the exam. Laboratory reports constitute 20% of the semester mark while large scale assessments in terms of common tests and semester tests constitute the bulk of the semester mark. Two semester tests are scheduled for the module. These are two-hour tests which usually cover three themes. Semester tests have a multiple choice section and a written section which includes a question per theme covered. Common tests are only a maximum of 50 minutes long and cover only one or two themes. Common tests are more frequent, scheduled three to four times over the semester. There is flexibility in the structure of common tests: they may be solely multiple choice, solely written, that is the answers to the questions are self-constructed, or a blend of the two.

The common tests serve as the data collection method for student performance in this study. There are several motivators for this: the frequency of the common tests allows for the effects of the interventions to be measured soon after implementation, limiting the effects of individual learning which would be present for semester tests. The scope of the common tests is narrower, therefore, stress on the student is not as high as in the semester test. The length of a common test is much shorter so student fatigue while writing will not be as high. And finally the flexibility of the structure expands their usefulness as a quantitative tool in this study.

3.8 SMALL SCALE PILOT OF CHEMORGANISERS

The Chemorganiser on oxidation numbers was the first piloted material (see Appendix C), used on a group of 25 students in 2012. The Chemorganiser format and content was identical to that of the original developers, Reid and Sirhan (2002). The group was encouraged to use the Chemorganiser individually as a pre-lecture activity before the content was covered in lectures or tutorials. "There was no pressure on the students to take them, to use them, or to use them in a specific way" (Reid and Sirhan, 2002, p. 67).

An anonymous questionnaire was developed to explore the students' experience with the Chemorganiser. This questionnaire, found in Appendix D, was used as a quick means of gathering data on the implementation of the Chemorganiser. Unfortunately, only four students were able to use the Chemorganiser prior to the lecture. On these grounds, it was decided that students could not be relied upon to use the Chemorganiser beforehand, without providing motivation to do so in the form of grade incentives (Hake, 1998, p. 70) such as online quizzes or quizzes at the start of the lecture (Seery, 2012). A more positive finding from the questionnaire was that the four students found the Chemorganiser easy to navigate and acknowledged it as a helpful tool for their understanding of oxidation numbers.

Unfortunately, no opportunity existed to pilot the POGIL intervention prior to the commencement of the study due to logistical constraints.

3.9 THEMES USED FOR THE INTERVENTIONS

When choosing themes within the first year syllabus in which to conduct the research, the researcher had to review all the available published units for POGIL and the Chemorganiser. Sixty Chemorganisers had been developed to choose from and POGIL worksheets were available from the manual *Chemistry, A Guided Inquiry*. Units that covered the same themes were flagged and then compared with the existing CMY 133 and CMY 143 syllabus – any units on themes outside the syllabus were discounted. Next the content and depth of the Chemorganiser and POGIL units were evaluated in comparison to the learning outcomes in the CMY 133 and CMY 143 syllabus – any topics that were not dealt with in the same intensity as the course required were discounted. Such a process ensured that appropriate intervention materials with only minimal alterations were used in the study, thereby minimising error or bias that the researcher may introduce if excessive editing was required or new materials need be developed for either the POGIL or the Chemorganiser. Finally the two themes decided upon were *The mole concept and stoichiometry* and *Redox reactions*. Both themes have been categorised as topics which chemistry students find challenging (Johnston, 2010) and as such add to the importance of the study.

3.10 TIMING OF THE INTERVENTIONS

The main determinant of the timing of the interventions was the selection of the themes *The mole concept and stoichiometry* and *Redox reactions.* Both of these themes are covered in the second half of the second semester CMY 143 course (from mid-September to November), leaving approximately ten days until the close of the semester and the beginning of the examination period.

The timing of the interventions had significant implications for the study. Firstly, as the interventions only take place in the second semester, students' first semester marks may be used to establish whether there is a significant difference between the groups (both experimental and control) in terms of ability. The students' performance in CMY 133 is a more reliable proxy for ability than matric results because of the uneven provision of science education in South Africa.

Another advantage of the timing of the intervention is that meaningful small group allocations for POGIL may occur based on performance strata. Data collection in the form of focus group interviews and a general questionnaire were planned for when the interventions were complete so that the students could provide well considered opinions on either their POGIL or Chemorganiser experience; the ten days before the end of the semester allowed sufficient time for data collection.

From a socio-cultural perspective, the students have experienced university life for the larger part of the year before they are exposed to the interventions. Thus students should have built up coping methods for non-academic distractors. Students should have also developed a rapport with their classmates as they were assigned to the same tutorial groups for the entire year.

While the timing of the interventions can mainly be considered advantageous for the study, there are obvious drawbacks when normal trends of class attendance, student health and fatigue are examined towards the end of an academic year. In addition to these challenges, students are faced with a large group assignment for another module in the final quarter of the year. It has been observed that students' poor time management affects involvement and attendance in other modules in which they are enrolled.

3.11 VALIDITY OF INTERVENTION MATERIALS

The POGIL guided inquiry worksheets (Appendix B) and the A4 Chemorganisers (Appendix C) were the intervention materials used in this study (as described in Chapter 2). Minor editing of the materials took place to streamline the content with the CMY 143 curriculum: editing was restricted to essential instances to maintain the integrity of the intervention materials. The researcher endeavoured to make use of high quality materials as this is a factor which would influence the success of the interventions.

Before using the materials in the study, both the guided inquiry worksheets and the Chemorganisers were checked by an external party for face validity, that is the consistency, presentation and layout of the material were evaluated. The external party is a highly experienced chemistry teacher and she made no objections to the intervention materials. Content validity was checked by the researcher as mentioned previously through minor editing. The content of the materials or curricular validity was also examined by the coordinator (and lecturer) of the CMY 143 module and was found to be aligned with the course outcomes.

3.12 SAMPLING

There are three criteria for a true experimental design, as specified by Maree (2007). Firstly, a manipulation or intervention should be implemented by the researcher. Secondly, a measure of control should be present in the form of a group that does not receive the intervention and/or a pre-test to measure the status of the sample before the intervention. Finally, the sample should be selected randomly so that the results are generalisable to the population.

As stated in the research design, the nature of this study is quasi-experimental: the first two criteria for a true experimental design are satisfied, however, the sample is not chosen randomly, but conveniently. Students are divided into pre-existing tutorial groups of approximately fifty at the beginning of each year and stay in the same group for the entire year, the researcher has no control over this process. The two groups chosen to undergo the interventions are those for whom the instructor is also the researcher. The remainder of the student body acts as the control and comprises of 250-300 students or five to six groups of fifty students. The student population of the extended programme is a blend of male and female students from various socio-economic backgrounds, however, the majority of the students are either weak academic performers or under-prepared for the challenges of main stream tertiary education.

3.13 DATA COLLECTION

Various forms of data collection methods were chosen to best answer each of the secondary research questions. The appropriate data collection strategy is given beside the corresponding research question below in Table 4. Only one data collection strategy is required to answer the first question, whereas a blend of strategies is the most appropriate way to answer the remaining research questions.

Table 4. Summary of data collection strategies.

Research Questions	Data Collection Strategy
1. How do the approaches influence student performance?	Student test performance
2. What are the impacts on the students' opportunity to learn within each approach? 3. What influence does each approach have on productivity, both inside and outside the classroom? 4. How are the approaches received by the students?	Instructor's Observations External Observations Student focus group interviews Student Questionnaire

The timing of the data collection strategies is also of importance and should follow the sequence of the CMY 143 course proposed below in Fig. 13 and Fig. 14. It was the intention of the researcher to follow the same time sequence in the first and second year of the study, however, the re-positioning of themes within the course required data capturing to be shifted. The alteration to the time table in the second year was anticipated to make data capture more challenging.

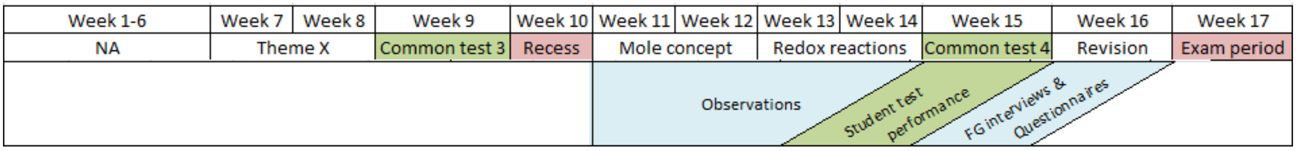

Figure 13. Sequence of data capturing in the first year.

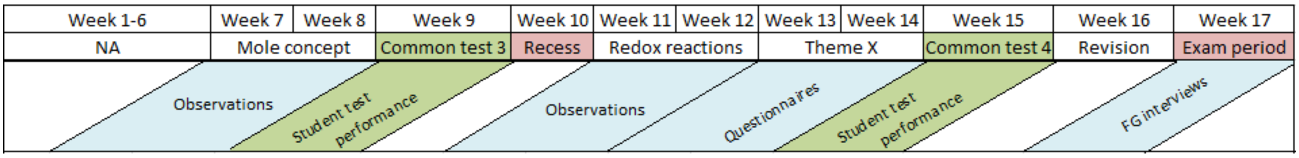

Figure 14. Proposed sequence of data capturing in the second year.

The following tables (5 and 6) describe each data collection strategy in detail: Beginning with the mode of documentation, then the value that the data collection should add to the study. The challenges and difficulties associated with each data collection strategy are also discussed. Each table ends with a justification of the selected data strategy within the study. Quantitative data collection methods are presented in Table 5 and qualitative methods in Table 6.

Each of the data collection strategies are introduced briefly before presentation in Tables 5 and 6. The first strategy is student test performance which was assessed using a common test (as described in Section 3.7). The common test in year one assessed both themes, whereas in the second year, two tests were required due to the sequencing of themes during the semester. The common tests used can be found in Appendix F.

The student questionnaire aims to collect the general opinion of the students who participated in the intervention. The questionnaire was distributed during a tutorial session to ensure a high rate of response and thus a more trustworthy and generalisable student opinion. Colleagues of the researcher were requested to administer the questionnaire, minimising any bias or sense of obligation that the students may feel in the presence of the instructor.

The questionnaire was based on the findings of the focus groups in the first year. Thus in the first year of the study it will be the final data collection strategy. In the second year, student questionnaires were administered before the focus group interviews. Students are often too pushed for time at the close of the semester to participate in focus group interviews; therefore interviews were conducted during the exam period in the second year. The questionnaire consisted of six closed questions with three to five response options for the students to choose from. The questionnaire should not take students more than 20 minutes to complete. The questions in the questionnaires were identical except for two questions that probed the efficiency of group dynamics for the POGIL group as compared to one question that asked about the efficiency of individual engagement for the Chemorganisers group (see Appendix E).

The focus group interviews were conducted in small groups of three or four students. Four sets of focus group interviews were conducted at the end of the first year of the study: two sets of POGIL focus group interviews and two sets of Chemorganiser focus group interviews. These were fully transcribed (see Appendix G). In the second year of the study, only one focus group was conducted per intervention group. Only pertinent quotes were used, the entire interview was not transcribed. By this stage, general student opinions had already been voiced through the questionnaire; the researcher used the focus group interviews as an opportunity to probe any final points. A representative subset of students in terms of performance was identified by the researcher in each year so that all students, both strong, weak and medium performers, are represented. Students eligible to participate in the focus group were invited to participate. Students who wished to participate, informed the researcher and the date and time of the focus group was negotiated. Students who participated in the interviews were compensated with a take away meal. All students, approximately 50 POGIL students and 50 Chemorganiser students per year, were provided with a chocolate at the end of the intervention as a 'thank you' for their efforts and patience.

In this study, the researcher was the instructor and as such had the role of participant as observer. The instructor was fully occupied in the teaching activity and could only note observations after the tutorial session in a journal. Reflections were added to the journal entries after time has elapsed (usually one day). Reflections should add to the richness of the data observed as thought has been given to the reasons behind the observations. Journal entries from the first year of the study were transcribed and are included as Appendix I.

In order to capture as much data as possible from the classroom environment, the help of experienced colleagues, was enlisted. Two observers, John and Jane, were chosen as the time required would be too much to ask of any one person (both observers are also instructors on the CMY 143 course). John is a middle aged family man whereas Jane is in her mid-twenties. Despite an age gap, both John and Jane have had similar amounts of experience in the instruction of chemistry. These two observers acted as participants in the study because they contributed to the data collection. They were primed to note student involvement and work ethic, the apparent degree of student learning, productive use of time and overall student enjoyment. External observations were conducted twice in a given year of study, once in the early stages of the interventions (John) and once in the later stages (Jane) to provide a time line. Observers were requested to submit a written account of their observations to the researcher and were invited to add their own reflections.

Table 5. Quantitative data collection methods

Data Collection Strategy	**Student test performance**	**Student Questionnaires**
Mode of documentation	* Common test * Test score recorded digitally in a spread sheet	* Students select a closed option * Responses recorded digitally
Value	* Raw or untouched data * All students write the same test * Little bias exists in the marking, as one marker is allocated per section, any bias will be consistent	* Quick for respondents to complete (20mins) * Respondents have time to think about questions (McMillan and Schumacher, 2010) * General opinions /trends of the sample are revealed * Ensures anonymity (McMillan and Schumacher, 2010)
Challenges	* Data may be entered incorrectly * Missing data (student is sick for a test) * Test difficulty and fatigue * Insufficient time allocated for test * Outdoor distractions during the test (e.g. noise) * Scheduling of test adding to student stress levels (students may be writing other tests on that day/week)	* It may be time-consuming to develop the questionnaire (Cohen et al, 2007) * Closed questions are "choice-forced" (McMillan and Schumacher, 2010) * Phrasing of questions may result in “leading” questions * Participants may misunderstand questions * Data may be entered incorrectly * Missing data (student may leave out particular questions) * Students may choose not to participate
Justification	The assessment experience of the experimental groups will be identical to that of the control group as the same test is written in one venue by all the students. Collecting data in this way is relevant to the quasi-experimental nature of the study as it allows for statistical comparison across groups, to judge the worth of each educational intervention in terms of student performance compared to the performance of a control group.	Questionnaires are one of the principle means of gathering survey data for a large sample, thus, it is best suited to the sample of approximately 100 students per year in this study (Maree, 2007). Questionnaires are widely used and it is very likely that student respondents will be familiar with how to use the instrument (McMillan and Schumacher, 2010). Group administration of questionnaires in a classroom setting will allow an optimal response rate opposed to online or postal questionnaires (Maree, 2007).

Table 6. Qualitative data collection methods

Data Collection Strategy	Focus group interviews	Participant as observer (Gold, 1985)	Observer as Participant (Gold, 1985)
Mode of documentation	* Tape recorder * Full transcription	* Journal entries * Reflections * Digitisation	* Observation schedules (Mulhall, 2003, p. 306) * Reflections * Digitisation
Value	* Fresh and open student opinions * Insights gained may be used to improve interventions * Opportunity for the researcher to probe existing findings * Individuals given a voice within the group * Less intimidating than a one-on-one interview * Short (±20 mins) and low cost	* Natural behaviour is seen in real-time * Verbal and non-verbal actions are recorded * An opportunity to collect unanticipated emergent data * The creation of a highly contextual understanding	* Natural behaviour is seen and recorded in real-time * Observer as participant is able to concentrate their efforts and may be more observant * The varying characteristics of the observers may result in a more holistic view of classroom behaviour
Challenges	* Highly time consuming data transcription * The interviewer may influence the respondents through: o the wording of the questions o the interviewer's responses to answers, including facial expressions and emotions * Some respondents may feel threatened in a group environment whereas others may dominate (Cohen, Manion and Morrison, 2007; Maree, 2007). * Capturing non-verbal cues	* Time consuming to observe and analyse * Misinterpretation of participants' actions * Introduction of bias in their choice of what is recorded * The presence of an observer may alter the participants' actions (McMillan and Schumacher, 2010).	* As for participant as observer * The manner of information collection is unique to the individuals collecting the data
Justification	Any type of interview would allow the researcher to probe the students' experience of the interventions. A focus group interview was chosen because different opinions can be argued and debated, not simply recorded (Maree, 2007). Richer data is acquired by this layering and intertwining of views in a social environment than could be gathered in a long-winded individual interview (Maree, 2007; McMillan and Schumacher, 2010).	Observation is unique in that it allows the researcher to "experience reality" in a similar way to participants (Maree, 2007, p. 84). Observations are valuable as they utilise different senses, for example, "Is the classroom noisy?" Other cues like tension or joy of the participants may be noted. Observation is crucial in this study: it will provide rich data, like the focus group interviews, but may not be as intimidating (a class of 50 students will be observed as opposed to three students in a focus group). Observation will also provide an overview of the behaviour within a class, whereas an interview or focus group will only probe this for specific individuals.	

3.14 DATA ANALYSIS

The various data collection strategies were aligned with the secondary research questions in the previous section (see Table 4). After collection, each data set was analysed using a specific analysis technique. Mindful of this, Table 7 and 8, link the chosen data analyses to the data collection strategies, which were informed by the research questions.

Before the implementation of the interventions, it was necessary to ascertain whether the control and experimental groups were comparable in terms of ability, if this was not the case, then any results of this study would be questionable. In the first year of the study, student's performance was used as a strategy for comparing the abilities of the three groups. However, in the second year, the semester test results of students enrolled in the second semester were used. The motivation behind this was that this data set already excluded students no longer registered in the course and as such minimised processing time.

Table 7. Data analysis strategy for the first research question.

Research Questions	Data Collection Strategy	Research Instrument	Data Analysis
1. How do the approaches influence student performance?	Analyse pre-intervention performance	Performance in preceding CMY course	Statistical analysis: descriptive and inferential
		Results of semester test	
	Analyse post-intervention performance	Student performance in a compulsory common test	

Non-parametric tests were used as student group sizes vary (≈ 300 control and ≈ 50 per experimental group per year). ***Descriptive*** statistical analysis portrayed the mean, standard deviation and distribution of each group. To meaningfully compare the differences in student performances across groups, ***inferential*** statistics were utilised. Ideally, the Kruskal-Wallis test should reveal that no statistically significant difference exists between independent pre-intervention groups. A difference was expected post-intervention, and to clarify where differences may lie, the post-hoc Mann-Whitney U Test will be used. Data was analysed at the standard 5% significance level, two-tailed test results were used. The aid of appointed research statisticians was relied upon for conducting the statistical analyses and for the interpretation of results.

Answering the research questions was the objective of this study, so this provides the issues or guiding themes behind the ***organisation*** of collected data. In the case of each research question (2, 3 and 4) the inductive and deductive analyses of data from various streams such as interviews, observations and questionnaires were collated to provide a joint answer to a research question as shown in Table 8 (Cohen et al., 2007).

Table 8. Data analyses strategies for the second, third and fourth research questions.

<table>
<tr><th>Research Questions</th><th>Data Collection Strategy</th><th>Research Instrument</th><th>Data Analysis</th></tr>
<tr><td rowspan="4">2. What are the impacts on the students' opportunity to learn within each approach?

3. What influence does each approach have on productivity, both inside and outside the classroom?

4. How are the approaches received by the students?</td><td>Instructor's Observations</td><td>Daily journal/notebook completed after class</td><td>Descriptive</td></tr>
<tr><td>External Observations</td><td>Observation schedule and own observations</td><td>Code, classify, categorise</td></tr>
<tr><td>Focus group interviews</td><td>Semi-structured interview questions</td><td>Code, classify, categorise</td></tr>
<tr><td>Questionnaire</td><td>Closed multiple choice questions</td><td>Statistical analysis: descriptive</td></tr>
</table>

The cornerstone of daily observations by the instructor was that it allowed for the participants' interactions to be analysed chronologically, bringing to light trends that emerged over time. Cohen et al. (2007, p. 461) state that approaches to qualitative data analysis are guided by the underlying concept of "fitness for purpose", that is the researcher must decide on the purpose of the data before attempting to choose a method of analysis. An analysis approach is composed of how the data is organised and how the data is presented. To ***present*** data for analysis, a "joint display" was used in Chapter 5 (Creswell, 2014). Results will be presented per instrument under a specific heading or issue. Cohen et al. (2007, p. 468) states that by presenting results by instrument, it is clear where the data is derived from and the integrity of the data derived from that instrument is preserved.

3.15 LIMITATIONS OF THE STUDY

The qualitative component within a mixed methods study limits the use of the findings, that is, any findings of this study are context specific. As the findings are unique to the participants and setting, it is up to the reader to appreciate the findings and apply them.

Another limitation within the study is that the processing of qualitative data is time consuming, thus it may limit the extent and quality of findings presented here within. It is the undertaking of the researcher to limit subjectivity and represent relevant and truthful findings.

As aforementioned, the researcher was also the instructor within this study, this has various implications on validity: The skill set of the researcher will affect the quality of the findings through data collection methods and analysis. The skill set and experience level of the instructor may impact on the delivery of the chosen interventions. Again, the researcher has endeavoured to be proficient in the means required to collect and appraise the data, and the instructor was familiar with the delivery of the materials and the pedagogy behind each approach.

Any pre-existing bias, albeit from the students or the instructor, will impact the study. Such biases may not be able to be controlled for, for example, the students' experience of group work at high school. Students may not participate or embrace the interventions fully, based on their prior experiences.

An instructor may have pre-existing perceptions about the merits of each of the interventions or a preference for either a more teacher-centred or a more student-centred instructional approach. However in this case, the instructor is not only a disciplinary expert (a scientist) but the instructor is also trained in pedagogy for teaching science. The instructor, who is also the researcher, entered the study with an open mind and a desire to find the most appropriate instructional approach for her context.

A further limitation, as mentioned in Section 3.8, was a lack of opportunity to pilot the POGIL intervention before implementation in this study. Piloting of the POGIL intervention may have allowed for any immediately noticeable challenges to be documented and corrected for in the first implementation.

A final limitation is reliance on chemistry tutors who were science graduates rather than student teachers to observe the experimental lessons. Their viewpoints as science educators may have created a bias in the observations; in further research of this type it may be valuable to call upon the expertise of educational psychologists or experts in science education to monitor the learning process and surrounding environment.

3.16 ETHICAL CONSIDERATIONS

Before the commencement of this study, ethical clearance was applied for and was obtained from the Ethics Committee of the Faculty of Natural and Agricultural Sciences at the University of Pretoria (see Appendix A). The study is aimed at improving standards of teaching and learning for first year extended programme students, thus the students themselves were the primary sources of data. Experimentation was a necessity in the study, neither intervention (be it POGIL or the Chemorganiser) was known to be disadvantageous to students at the commencement of the study.

The educational interventions were also not intended to offer exclusive advantages to any participants as the content covered was identical in each case. Variation already exists in the teaching styles of the small group tutorial instructors, and as such, deliberate variation of teaching styles of one instructor should not be viewed as extraordinary.

The large group lecturer remained the same for all students, again emphasising that all students would be exposed to the same content and teaching style when attending lectures. Small group tutorials are additional to the course, although attendance is compulsory.

The consent of the students in the experimental groups was gained through a signed letter after the interventions were explained. Students also received an informative letter further explaining what they could expect during the interventions e.g. to be observed or to fill in a questionnaire (Appendix A). All students were over eighteen at the start of the study. Some students declined to participate in interviews but all students in the experimental groups underwent the intervention.

Student test scores and questionnaire responses were treated as anonymous. The identity of focus group interview participants was kept confidential. The observations of instructor and external observers were kept impartial to student identity.

The findings of this study will not only be shared within foundation chemistry and other members of the extended programme staff but will be presented at conferences and published if possible. The sharing of the findings and reflective activities of this study may provide other educators with successful means of learning for students, or inspire new teaching ventures grounded in scientific theories and educational principles.

3.17 SYNTHESIS

In attempting to gain more holistic measures of effectiveness, the researcher took a pragmatic stance which embraced both the subjective and objective for the most valid conclusions to be drawn. Mixed methods research was conducted, that is the blending of qualitative and quantitative data collection strategies to answer each research question.

CHAPTER 4: PROVISIONAL FINDINGS AND REFINEMENT OF STUDY

4.1 INTRODUCTION

This chapter serves as a bridge between the planned research design and methodology of Chapter 3 and the final results which agree presented in Chapter 5. In this chapter, provisional findings after the first year of study are shared with the reader. These findings were causes for pause and reflection before embarking on the second year of study. The chapter concludes with the proposed areas of refinement in each intervention.

4.2 PROVISIONAL FINDINGS

In this section, poignant findings from the first year of study will be briefly highlighted, so as to not detract from the overall results presented in the following chapter. The findings of the Chemorganiser intervention will be presented first followed by the findings of their POGIL counterparts.

In the first year of the study, the Chemorganiser was well received by the majority of students, and increased classroom participation was noted along with stable levels of attendance. This intervention did not affect the time allocated for the tutorials and was easy to implement. A few students voiced difficulty in adjusting to a new teaching style and some students requested more challenging content to be covered using the Chemorganiser. As students became accustomed to the use of the Chemorganisers, it was observed that some students lost focus during the discussion; this was reiterated in the focus interviews when students commented that they were bored during discussions.

On the other hand, students who experienced POGIL were unhappy and class attendance dwindled. Some students used group work as an opportunity to pass the work on to other members. Other students felt that the assigned roles were superfluous on occasion and this resulted in boredom and a lack of involvement. Students battled to get through the work in the time allocated, requiring twice the time to be spent on the same content. Students often found group work challenging, one reason for this was found to be social discomforts caused by the members' cultural diversity and, as a ripple effect, the power play in a group. By allocating students into heterogeneous groups, it was evident in some situations that stronger students felt frustrated and weaker students felt exposed or vulnerable, students also voiced these opinions in the focus group interviews.

Other practical findings emerged from the first year of implementing POGIL: Due to the nature of this intervention, the venue required was different to the venue to which the students were accustomed, this was distracting for the students and difficult for the instructor to facilitate unaided.

4.3 ACTION RESEARCH

Mixed methods may be blandly viewed as collecting and analysing various forms of data using triangulation as a means to find the ultimate truth of the situation (Creswell, 2011). The pragmatic nature of this study and of mixed methods itself, call for more reflection and a deeper understanding of the participants and context of the study, hence action research was embarked upon. Action research can be undertaken in a variety of forms (Cohen et al., 2007, p. 297) and can be hybridised with the interpretations and implementations of the researcher (Maree, 2007, p. 129). In this case the undertaken action research did not overshadow the mixed methods design or quasi-experimental nature of the study, but unobtrusively blended into it for the benefit of the researcher and the participants. Lingard, Albert and Levinson (2008, p. 460) expand on this notion by emphasising that action research seeks to meet the needs of both the researcher and the participants, who are termed collaborative partners in the research.

Thus the study moves from seeking which intervention is most effective for the sample to improving the interventions to meet the needs of the students. This approach is in line with the stance advocated by Grayson (2014) to "meet students where they are" and elevate and educate them, not to expect students to cope with whatever educational means we, as educators, choose to employ. The following statement by Sirhan et al. (1999, p. 46) is useful to exemplify 'meeting students where they are' in the context of extended programme students, "the confidence and motivation of more poorly qualified students will almost certainly be enhanced by learning experiences where their weaknesses were being taken into consideration."

Although the quasi-experimental design is repeated in both years of the study, findings from the first year of the study were appraised by the researcher in the role of a reflective practitioner. By including a second year of study, the researcher is allowed the opportunity to reflect upon the findings and attempt to better suit the interventions to the needs of extended programme students in the second year of the study. Horwood (1995, p. 227) provides insight as to what reflection entails, "the thinking involved must scan memory of the past, seeking connections, discrepancies, meanings". Horwood goes on to say that the reflective process may be enriched over time as memories and observations may take on new meanings. Smith (2010, p. 5) adds to the notion of reflection as being a systematic process taken on by the researcher as practitioner. In the case of this study, all reflections will be guided by the initial research questions.

The figure below shows the research strategy that will be followed, incorporating elements of action research, to tie together the first and second year of this study in a meaningful and ethical manner. Maree (2007, p. 74) refers to action research as a cyclic process, as illustrated in Fig. 15, in which data is collected, analysed, used to evaluate a problem and then the process is reviewed. Case and Light (2011, p. 196) define the aim of action research to be the "strategic improvement of practice" and point out that action research is a unique research design as the researcher is also the educational practitioner. Lingard et al. (2008, p. 461) provide a neat summary of the essence of action research, as an "iterative process in which researchers and practitioners act together in the context of an identified problem to discover and effect positive change within a mutually acceptable ethical framework".

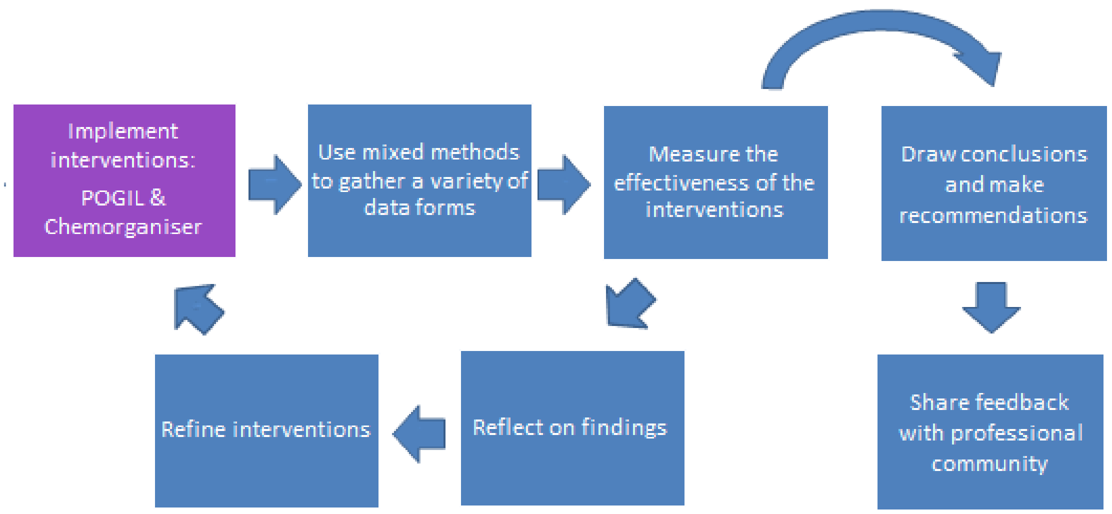

Figure 15. Proposed cycle of action research for the study.

Johnson and Onwuegbuzie (2004, p. 18) refer to a characteristic of pragmatism as a drive to create "practical theory" or "theory that informs effective practice". Re-implementation of modified POGIL and Chemorganiser interventions in the second year should not alter the essence or integrity of each intervention but add to the applicability of the intervention to the sample.

By embarking on action research in the course of this study, more meaningful comparisons of the interventions, in the context of foundation chemistry, may be drawn and shared with the professional community. Such a sharing of knowledge and experience is encouraged (Smith, 2010, p. 7) as it is both valuable and may be influential in the field (Clayton, 2011, p. 5). To close, the statement by Horwood (1995, p. 228) is relevant, "Professional knowledge and knowing comes much more from reflecting on practice than from applying theoretical ideas".

4.4 AREAS OF REFINEMENT

Upon reflection, the innovations were refined in an effort to strive to enhance the effectiveness of both the POGIL and the Chemorganiser approaches for foundation chemistry.

The changes made to the implementation of Chemorganisers included the addition of more challenging worked problems where necessary, without removing the original worked problems. Thus the content was not changed overall, but merely expanded upon to include worked examples of a similar demand level to assessment problems. In the first year of the study, each Chemorganiser was discussed in detail at the beginning of a tutorial; this took approximately 20 minutes. When re-implementing the Chemorganiser approach in year 2, the length of this discussion was reduced to a maximum of 10 minutes. Students were encouraged to interact with the Chemorganiser as an individual tool.

The content of the POGIL worksheets remained unchanged. The changes made to the implementation of POGIL were threefold: Grouping structure and the reduction in the size of groups, alterations of the members' roles and the introduction of guiding time allocations per question. To ease social discomforts, it was decided that students should be allowed to choose their own groups in the POGIL approach. This flexibility should also solve the problem of absenteeism as students only form groups with other students in attendance. In the second year of the study, small POGIL groups consisted of three members in an effort to increase individual responsibility and involvement. The roles were condensed from five (see Section 2.2.6) to three. Each group had a manager, a recorder and a "general secretary" who kept time and was responsible for all technical work like operating the calculator. The role of presenter was omitted in the second year as not enough time was available in a tutorial session for presentations. The role of reflector was also omitted as analysed reflections in the first year of study did not appear to be honest or meaningful.

4.5 SYNTHESIS

The direction of this study was altered by the poor findings for those students who experienced the POGIL intervention during the first year, including poor attendance, late-coming, poor attitude, lack of diligence and motivation and finally poor grades results. Action research provided an opportunity to refine both interventions with the aim of increased effectiveness, taking into account the needs of the students and the instructor. Thus, the results from year 1 to year 2 often differ greatly as discussed in Chapter 5. The primary refinements were the alteration of the group work structure in which students may select their own group members and decide on their roles in slightly smaller groups within the POGIL classroom.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 INTRODUCTION

In this chapter, findings from both the first and second years of the study are presented. The chapter begins with an analysis of student performance; firstly by comparing the groups' performance in a given year and then noting shifts in performance trends from year 1 to year 2. The second half of the chapter deals with joint displays of data, each joint display having a heading drawn from the graphical representation of emergent findings. The findings on the joint display are presented in terms of the instrument used to gather the data (see Section 3.13). The chapter concludes with a discussion of the results in terms of the research questions, seeking to answer the ultimate question of the effectiveness of each approach.

5.2 STUDENT PERFORMANCE: YEAR 1

5.2.1 PRE-INTERVENTION PERFORMANCE

First semester CMY 133 results data were cleaned to correct for any student attrition, once student numbers were finalised for the second semester. Two data sets were analysed: students' semester mark before the exam and students' final mark before admission to supplementary exams. The semester mark was considered as students grades were based on six months of work, and as such would more accurately reflect student ability. The addition of an exam mark to the semester mark created a final mark for students, no supplementary exam data was added as it may boost the final marks unrealistically. Non-parametric statistical analysis as described in Section 5.2.2 was used to compare three groups for both data sets; the semester mark and final mark. No statistically significant difference was found between the three groups for each data set, $p=0.340$ and $p=0.178$, respectively.

Thus, both student performance data sets (semester marks and final marks) yielded the same results. The assumption that no statistical bias based on prior student performance was introduced into the study is now doubly valid. When determining the effect of interventions to the experimental groups, student ability was considered as a controlled variable.

5.2.2 POST-INTERVENTION PERFORMANCE

The results from the final common test (Figure 13, Section 3.13) were used to measure post-intervention performance. In this year, the common test comprised of two sections: a multiple choice section which is graded digitally and a written section with self-constructed answers which is manually graded by the assessor. The multiple choice section contained questions relating to both the ***mole concept and stoichiometry*** and ***redox reactions***. Only one question dealing with a redox reaction made up the written section (see Appendix F). The data for both sections were analysed using the non-parametric Kruskal-Wallis test as group sizes varied. At the 5% significance level, no statistically significant difference was seen across the three groups for the multiple choice section (p=0.516) as shown in Fig. 16 below. It could be argued that in this instance, the opportunity for guess-work and rigid mark allocation created an equalising effect on the students' marks, making them unsuitable for use in this study. As such, no multiple choice components were employed in year 2.

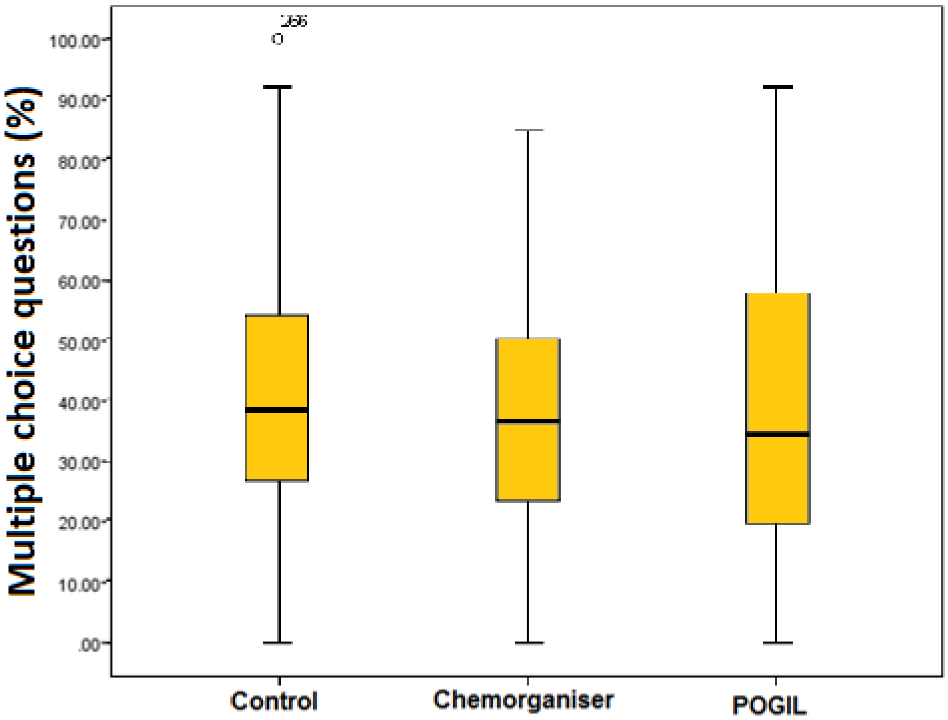

Figure 16. Box and whisker plot of multiple choice performance in Year 1.

When analysing the student performance on the open-ended or written redox question, using the Kruskal-Wallis test, a significant difference was found (p<0.0001) between the three groups at the 0.05 significance level. To clarify where this difference lay, the post-hoc Mann-Whitney U Test was used. The findings were as follows when taking into account the Bonferroni correction factor (0.05/3 groups = 0.0167): No statistically significant difference was found between the control and the group of students undergoing the Chemorganiser approach (p=0.026), see Fig. 17 point **a**. Highly statistically significant differences (p<0.0001) were found between the POGIL-experimental and the other two groups, with students undergoing the POGIL approach scoring lower marks than their counterparts, see Fig. 17 points **b** and **c**.

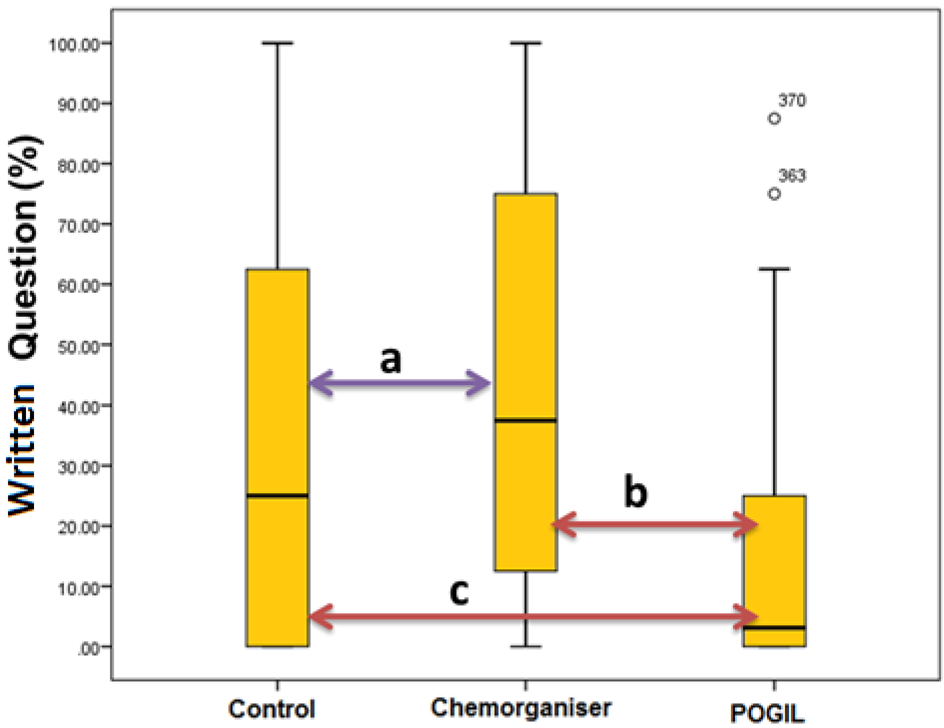

Figure 17. Box and whisker plot of academic performance in Year 1.

In general student performance was poor in the written question with a mean of 33.6% for the control, 45.2% for the Chemorganiser group and 14.5% for the POGIL group. Such a trend suggests that the level of the test was over-pitched, or that students find questions on ***redox reactions*** very challenging. Be that as it may, there is still value in the comparison of the performance, as all groups were exposed to the same standard of assessment and grading. The Chemorganiser students did achieve higher scores on average than the control; although this was not proven to be statistically significant, it does not discount any practical, educational and psychological significance in the Chemorganiser group's result (Maree, 2013). What was especially surprising and informative was the fact that student performance in the Chemorganiser group was significantly better than in the POGIL group.

A shortcoming of the data collected in the first year is that written assessment data was only captured for ***redox reactions***, the multiple choice data did not give sufficient information on the effectiveness of the interventions in terms of the ***mole concept and stoichiometry***. It was the aim of the researcher to address this shortcoming in the second year of the study, to strengthen the quantitative findings presented.

5.3 STUDENT PERFORMANCE: YEAR 2

Despite plans for two common tests to be written in the second year of study (See Fig. 14, Section 3.13), only one performance data set was gathered. Administrative challenges outside of the control of the researcher arose regarding the common test assessment of ***redox reactions***. Therefore only the analysis of student performance in the ***mole concept and stoichiometry*** common test (which can be found in Appendix F) will be described in Section 5.3.2. This is an unfortunate limitation on the versatility of the quantitative findings of this study.

5.3.1 PRE-INTERVENTION PERFORMANCE

Student results based on their most recent semester test written in semester 2 were used instead of first semester results or final marks as in year 1. Both proxies for student ability, were considered equally valid for the purposes of this study. Such a change in year 2 minimised the data cleaning required as no student data pertaining to student dropout needed to be considered. No significant difference was found using the Kruskal-Wallis test in performance between the control, Chemorganiser and POGIL groups prior to the intervention at a 5% significance level (p=0.133). The spread of the data for each experimental group was comparable as seen in Fig. 18.

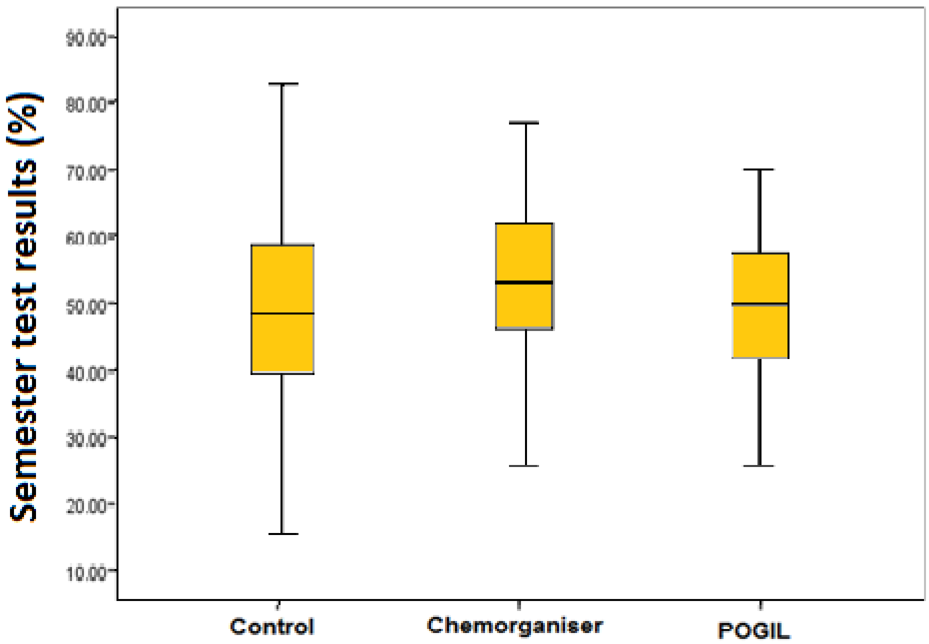

Figure 18. Box and whisker plot of pre-intervention academic performance in Year 2.

5.3.2 POST-INTERVENTION PERFORMANCE

On average, the group of students who underwent the Chemorganiser approach, achieved significantly higher grades (mean=70.0%) than that of the control group (mean=54.8%) (p=0.010), see Fig. 19 point **d**. No statistical difference was noted between the performance of the

Chemorganiser group and POGIL group in the second year of the study, see Fig. 19 point **f**. However, the performance distribution was narrower for the Chemorganiser group (standard deviation = 19.7% when compared to the POGIL group, 28.1%); this is especially visible when Fig. 19 is compared to Fig. 18. The spread of post-intervention performance is easily seen in Figure 19. This finding for the Chemorganiser group suggests that the weaker students within the group gained significantly from this intervention to reduce the gap between them and stronger students.

Unlike year 1, there was no significant difference between the achievement of the POGIL group (mean=58.2%) and the control (mean=54.8%) (p=1.00), see Fig. 19 point **e**. This finding suggests that the re-implementation of POGIL has increased its effectiveness from year 1 to year 2. The statistical techniques employed were the same as for year 1, Kruskal-Wallis Test (at a significance level of 5%) followed by Mann-Whitney U Test (Bonferroni correction applied p=0.05/3).

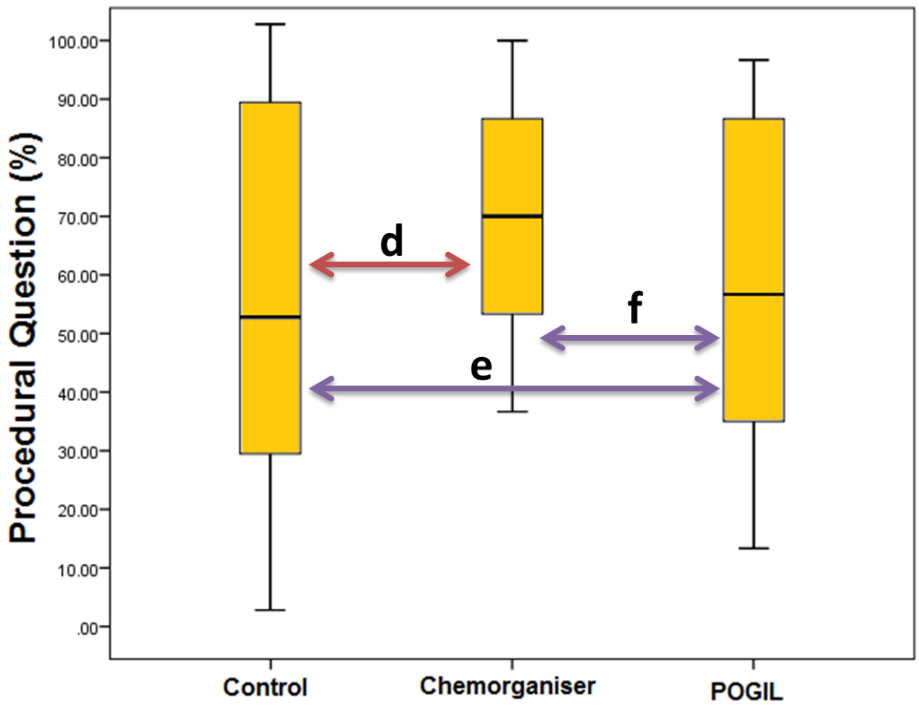

Figure 19. Box and whisker plot of post-intervention academic performance in Year 2.

5.4 EMERGENT THEMES

Before introducing the remainder of the findings, the researcher has sought to organise the variables which link the four principle constructs (conceptual framework, Section 2.5.3) with other inductive or emergent themes from the data. A diagrammatic model of the emergent themes is given in Fig. 20. The aim of such a model is to provide structure to the findings which researcher has gathered so that a better understanding of the results may be achieved.

The researcher has sought to categorise emergent, expectant and speculative notions under the headings of Nature of the task, Classroom dynamics, Emotional responses and Student behaviour. There is a link between these categories, which is posited in the diagram. All of the categories are influential on the final output of student performance and thus effectiveness.

At the core of this model is the potential notion of 'cause and effect'. For example, how will group work alter student behaviour through an emotional response to the classroom dynamics associated with the task? How will this impact on performance and overall effectiveness?

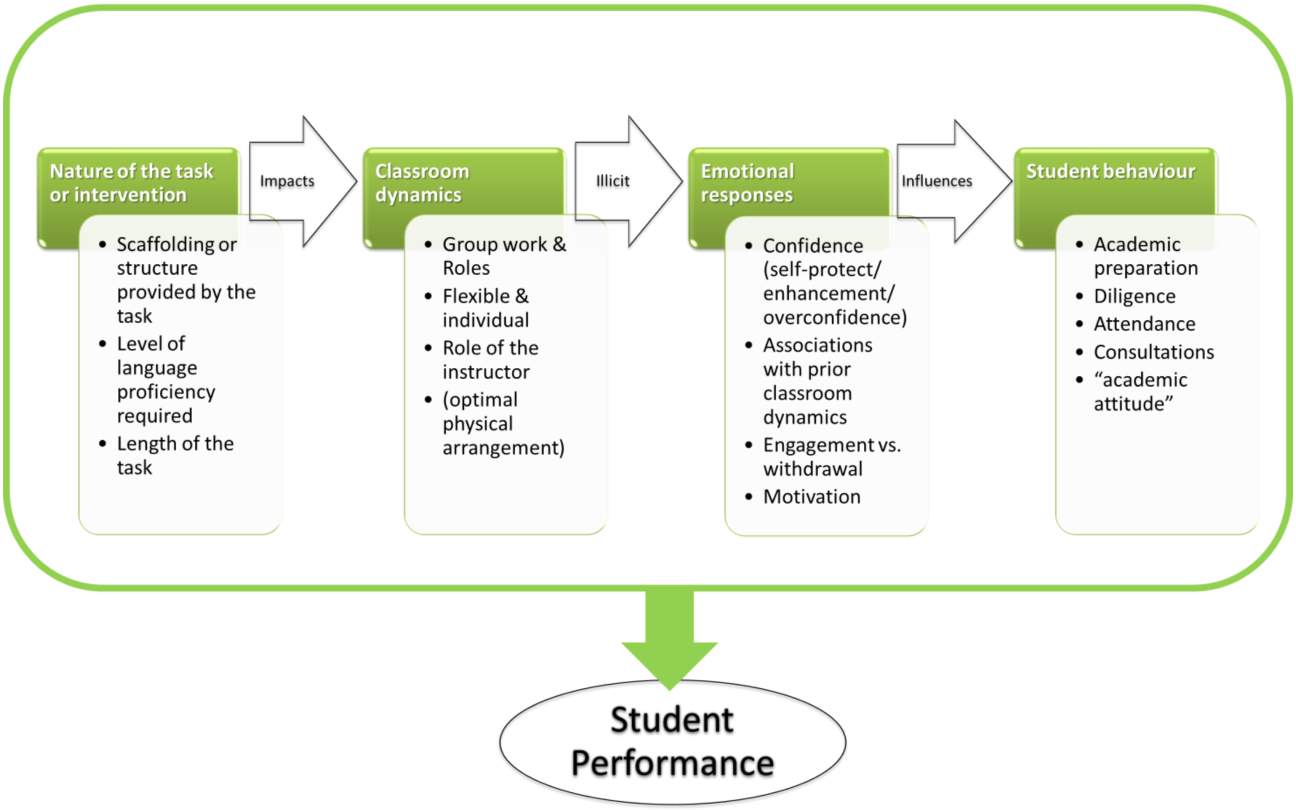

Figure 20. Emergent themes proposed by the researcher.

5.5 JOINT DISPLAYS

Joint displays represent a powerful and meaningful strategy of mixed methods data analysis (Creswell 2014a, 2014b). In the case of this study, both qualitative and quantitative data collected over a two year period is represented side by side according to specific categories which were given in the previous section. Select researcher's observations, chemistry colleagues' observations, quotes from focus group interviews and finally a graphical representation of student opinions from the questionnaire are presented on a single page.

Relevant observations and reflections of the instructor were grouped under a specific theme. A short paragraph was synthesised from this information for both the POGIL and Chemorganiser intervention and included under the heading "Instructor's observations" in Tables 9 to 12.

Referenced excerpts from the reports of the external observers (Appendix H) are used in the joint displays. These excerpts span the two years of the study. The excerpts are numbered with superscripts and the page number in the appendix is also given for ease of reference. John observed both interventions soon after implementation began. This data is labelled as **early intervention** in the joint displays. Unfortunately John was not available to observe the sessions in the second year of the study. Jane conducted observations towards the end of the interventions when the novelty of the intervention began to wear off. This was done for both years. The data from her reports is labelled as **late intervention**.

Focus group interviews were conducted at the end of the interventions in both years. Anonymous quotes from the focus groups are included and are referenced in the same manner as the external observations. Quotes from the first year of the study are referenced as they were fully transcribed (Appendix G). Referencing was not possible for quotes from the second year of study due to time constraints, this is an unfortunate limitation of the study (see Section 3.15).

The data from four of the six questionnaire items are graphically presented in the joint displays. Due to restrictions of space due to the nature of a joint display, a legend will not be provided with each graph. All data referring to **Chemorganisers** will be given in **blue** and data referring to **POGIL** in **orange**. The response rate for the Student Questionnaire was 78% for POGIL and 52% for the Chemorganisers in the first year and 56% and 77%, respectively, in the second year of the study. Such figures are not due to the refusal of participants but reflect the proportion of students in each group in attendance at the end of the semester. The researcher acknowledges that the opinions portrayed are therefore not those of the full cohort in each case: the smaller the response rate, the less reliable the questionnaire data will be.

The data is selected from each source based on a specific theme; that is, the data is already processed, analysed and organised in a manner which allows the comparison or triangulation of findings across data sources. In this section, four joint displays will be presented:

- The influence on Involvement/Engagement (discussed in Section 5.7.2)
- Preparedness for Assessment and Confidence in Achievement due to meaningful learning (discussed in Section 5.7.2)
- Productivity in class time (discussed in Section 5.7.3)
- Academic attitude and preference(discussed in Section 5.7.4)

Relevant joint displays, along with the additional findings (Section 5.6), will be grouped together to answer a specific research question. This approach will be used in so far as possible to provide trustworthy answers in Section 5.7.

Table 9. The influence on Involvement and Engagement

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External Observations

POGIL

“Perhaps the fastest ones in a group got bored, but they could alleviate that by teaching some of their slower peers[1]” John, **early intervention**, Year 1, p. 144

“the stronger and faster members have a tendency to leave the weaker and slower members behind and as a result majority of the students said that they would prefer to work on their own at their own pace[2]” Jane, **late intervention**, Year 1, p. 146

“I found that group dynamics wasn’t as big a problem this year[3]” Jane, **late intervention**, Year 2, p. 148

“This year group members were allowed to choose the role that they would play in the group. These roles suited the shy and more insecure students a bit better as it did not put unnecessary pressure on them to present[4].” Jane, **late intervention**, Year 2, p. 148

Chemorganiser

“In many instances (students) started asking more in-depth questions targeted at improving knowledge and understanding.[5]” Jane, **late intervention**, Year 1, p. 149

“The students also took the time to explain the Chemorganiser to each other when they did not completely understand something[6]” Jane, **late intervention**, Year 2, p. 149

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Instructor’s Observations

POGIL: Withdrawal of weaker students was noted over time despite allocated roles. Students disclosed they did not want to slow down the group so they would pretend to understand. Often stronger students became frustrated with the pace or their group members and would prefer to tackle the tasks alone or disengage from the group.

In the second year, such trends were not noted. Members seemed more comfortable in groups of their own choosing. Flexibility of roles was introduced and worked well.

Chemorganiser: Emotional responses to the Chemorganiser were positive. Engagement increased with stronger students asking more detailed questions and weaker students being confident enough to engage with peers or the instructor to seek help. Findings were applicable to both year 1 and 2.

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Focus Group Interviews

“If I was given, um a role for presenting I would be scared like the whole session that I have to speak in public and stuff. I couldn’t really concentrate[7]” **POGIL Year 1, p. 134**

“If you didn’t understand, you would find some students already moving on” **POGIL Year 1**

“I feel like I was wasting time, I could do it on my own and have my own questions (instead of answering others)” **POGIL Year 2**

“Normally, if I get stuck on the questions, then I lose interest and I don’t want to participate but the Chemorganiser, if I’m stuck, then I know I’ve got a guide to help me through it. So like recently, I’ve been tackling all the problems[8]” **Chemorganiser Year 1, p. 140**

“I am happy, I could do the whole theme” **Chemorganiser Year 2**

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Student Questionnaire Results

POGIL: “How did you feel about working in a group on an on-going basis?”

Chemorganiser: “How did you feel about using the CHEMORGANISER individually on an on-going basis?

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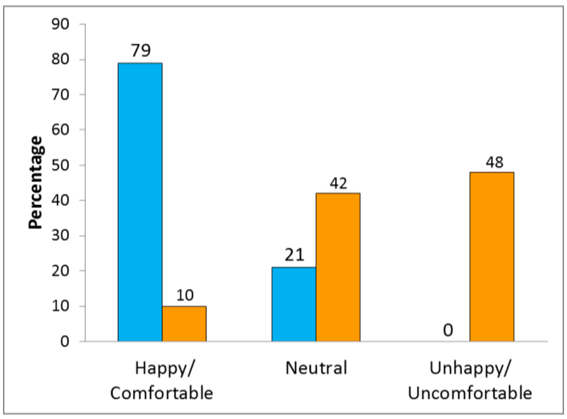
Year 1



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Year 2

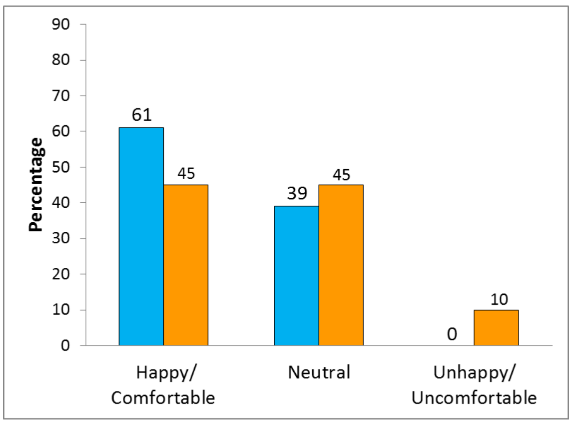

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Table 10. Preparedness for Assessment and Confidence in Achievement due to meaningful learning

<table>
<tr>
<td>External Observations
POGIL
"Are they learning? I'd say they are getting a different way of learning, I think it is a good way to get concepts across[9]" John, early intervention, Year 1, p. 144
"only approximately 25% of the students would have learnt anything from the session, while the other 75% have not learnt much at all[10]" Jane, late intervention, Year 1, p. 145
"students felt as if they were not getting enough feedback regarding the work[11]" Jane, late intervention, Year 1, p. 146
"I was very concerned about how naive the students appeared about the complexity of the work and how they all seemed to be overestimating themselves[12]" Jane, late intervention, Year 2, p. 149
Chemorganiser
"I don't know if there was the same level (of learning as in POGIL)[13]" John, early intervention, Year 1, p. 144
"the majority of the students appear to be learning and managing to successfully complete the problems[14]" Jane, late intervention, Year 1, p. 146
"students realised very quickly when they did not understand something and sought help[15]" Jane, late intervention, Year 2, p. 149</td>
<td>Instructor's Observations
POGIL: At the beginning of the intervention in the first year of the study, students appeared happy in terms of learning. With time, and as the challenges of the content increased, students became unsure of their answers (lacking confidence). As a result students requested model answers (these could not be provided as they were not in keeping with POGIL) therefore more demands were placed on the instructor's time by the groups for discussion and "checking" the answer. Year 2 did not follow the same trends. Learning proceeded meaningfully until students were faced with very challenging multi-faceted problems. At this stage some students were frustrated and others withdrew.

Chemorganiser: In both year 1 and 2, as the students engaged more with the Chemorganisers, the more confident they felt in terms of mastery of the materials and confidence in upcoming assessments. The materials appeared to "de-stress" the students.</td>
</tr>
<tr>
<td colspan="2">Focus Group Interviews
"When I get stuck I just lose concentration and I don't do work anymore. That kinda made me fall behind. So when it came to tests and stuff, I had to start from the beginning and do self-study[16]" POGIL Year 1, p. 133
"The common test, the last question was very relevant to the latest POGIL session… If I hadn't done the tutorial, I don't think I would have got any marks[17]" POGIL Year 1, p. 133
"It is not always chemistry like you are going to see in the exam, it's applications to like 'tree stumps'" POGIL Year 2
"We are not sure if our answers are correct, and if we learn the wrong step we will apply the wrong step" POGIL Year 2
"The questions given to us in the class were very similar to those we experience in the test." Chemorganiser Year 1
"I definitely feel well prepared[18]" Chemorganiser Year 1, p. 138
"Chemorganisers really helped the most for the test!" Chemorganiser Year 2</td>
</tr>
<tr>
<td colspan="2">Student Questionnaire Results
"Do you feel adequately prepared your for tests and exams?"</td>
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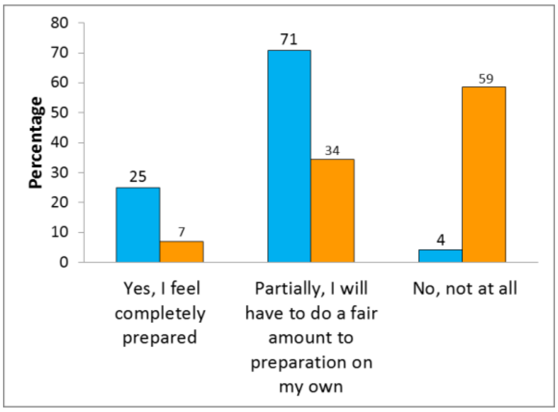
<tr>
<td>Year 1

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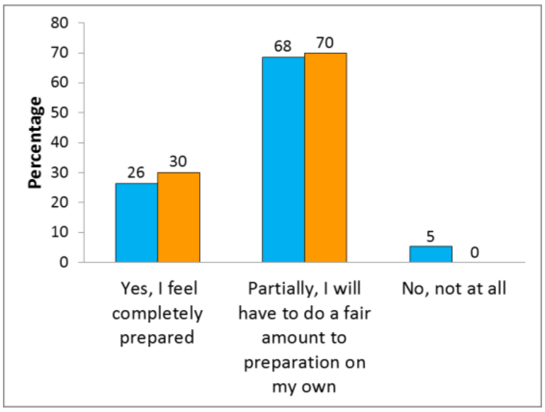
<td>Year 2

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Table 11. Productivity in class time

<table>
<tr>
<td>External Observations
POGIL
"I think it was a fairly productive way of using time to gain and share with each other[19]" John, early intervention, Year 1, p. 144
"My initial impression of the session was that it took some time for the students to sort into groups, followed by some more time to settle down and actually start working[20]" Jane, late intervention, Year 1, p. 145
"the students battled to use the allocated time well and most failed to complete the worksheet in the time available[21]" Jane, late intervention, Year 1, p. 145
"stages where the entire group was distracted and involved in a conversation about other topics (especially the groups of friends)[22]" Jane, late intervention, Year 2, p. 148
Chemorganiser
"The class was pretty quiet[23]" John, early intervention, Year 1, p. 144
"the students settled down and were ready to work very quickly[24]" Jane, late intervention, Year 1, p. 146
"When it comes to the productive use of time the students used the allocated time very well and most of them managed to complete the work assigned in the time available[25]" Jane, late intervention, Year 1, p. 146 and Year 2, p. 149</td>
<td colspan="2">Instructor's Observations
POGIL: At first, the increase in productivity from the original tutorial structure to using POGIL was remarkable: students surpassed all expectations. By the third tutorial productivity began to slump. Re-shuffling of the groups did not have the desired effect: some students never adjusted to their groups and overall productivity was at its lowest.

The second year was very different: time allocations were added to the POGIL worksheets and students were encouraged to measure their time against it. Students were encouraged to either move to the next question or seek help from the instructor. Students worked efficiently, however, when the questions were challenging, most could not stick to the time allocations. Many students gave up, but some students persisted doggedly.

Chemorganiser: In both year 1 and 2, levels of classroom productivity were pleasing and increased over time. Often students had to be encouraged to engage with the resources at the beginning of the interventions – they were not immediately productive on their own.</td>
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<tr>
<td colspan="3">Focus Group Interviews
"We were not able to cover a lot of work, I think we were able to cover the most important stuff and then after that you can also go home and find out for ourselves[26]" POGIL Year 1, p. 132
"We got to move at a faster pace or a slower pace depending on what was needed[27]" POGIL Year 1, p. 135
"We didn't always get to the end of the questions[28]" POGIL Year 1, p. 133
"I felt like POGIL's pace was a little too fast" POGIL Year 2
"Previously we tackled half the questions that you're giving us during the tutorial, now with the Chemorganiser we tackle most of the questions[29]" Chemorganiser Year 1, p. 140
"I felt that I could go at a steady pace as I am understanding" Chemorganiser Year 2</td>
</tr>
<tr>
<td colspan="3">Student Questionnaire Results
"How much time was used productively during the tutorial?"</td>
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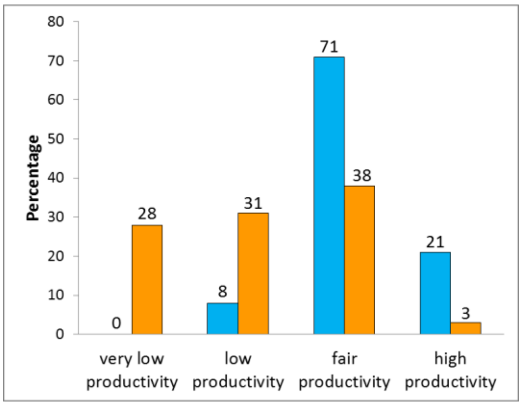
<tr>
<td>Year 1

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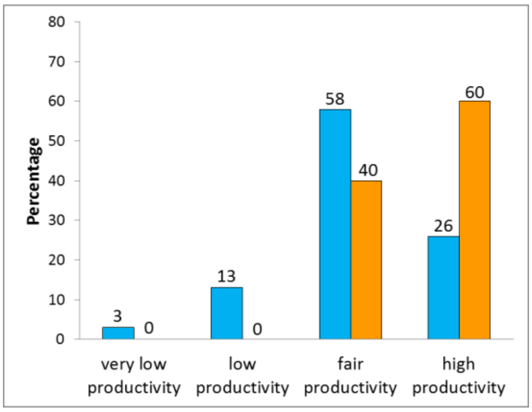
<td colspan="2">Year 2

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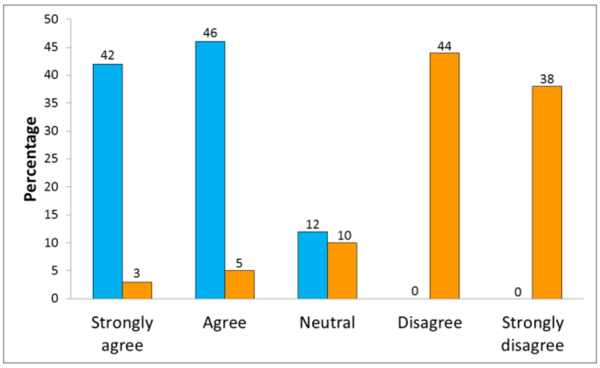
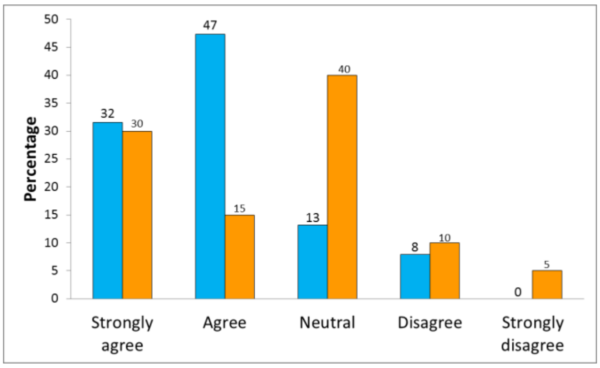
Table 12. Academic attitude and preference.

External Observations	***Instructor's Observations***
POGIL "Did they enjoy it, yes, I think most did[30]" John, **early intervention**, Year 1, p. 144 "I found that the students did not enjoy working in groups[31]" Jane, **late intervention**, Year 1, p. 145 "Many of the students… thought that the session had been a waste of time[32]" Jane, **late intervention**, Year 1, p. 146 "This has generated a very negative attitude towards the group work and POGIL and it has thus resulted in a negative attitude towards chemistry which may be difficult to undo[33]" Jane, **late intervention**, Year 1, p. 146 "I found that the students enjoyed working in groups and that they liked POGIL (I thought this a bit contradictory to the groan the students gave at the start)[34]" Jane, **late intervention,** Year 2, p. 148 **Chemorganiser** "I'd say they appreciated the new angle, more notes on the topic[35]" John, **early intervention**, Year 1, p. 144 "the students really enjoyed the Chemorganiser style of teaching and this was largely due to how structured and focused it was[36]" Jane, **late intervention**, Year 1, p. 146 and Year 2, p. 149 "This method has generated a very positive atmosphere in the class[37]" Jane, **late intervention**, Year 1, p. 160	**POGIL:** At first some students were weary of group work. Most students engaged in the new intervention eagerly and produced pleasing results. Student attitudes towards the intervention became increasingly negative with time. Comments such as, "Do we HAVE to do POGIL again today?" and "Can't we go back to the old tutorials?" were voiced in the tutorials. Towards the end of the intervention, students appeared to have 'given up' and a sense of gloom overshadowed the classroom activities. In the second year, student attitude did not decline as rapidly. Some students looked forward to the POGIL sessions. Student preference appeared mixed. **Chemorganiser:** Students were excited to collect the resources at the beginning of each session. Their enthusiasm grew as the intervention progressed. Students requested more Chemorganisers and suggested Chemorganisers for other subject like maths and physics. In the second year, students did not seem as enthusiastic and took longer to warm to the intervention. However, overall student attitude was still positive.
Focus Group Interviews "I hate teamwork and I don't think sometimes it's productive. So I wouldn't recommend POGIL[38]" **POGIL Year 1, p. 136** "To an extent I did enjoy it. It helped me in some senses. I would agree with using POGIL again[38]" **POGIL Year 1, p. 136** "I also like doing my work individually but after that to check my answers I would like to discuss it with my group[40]" **POGIL Year 1, p. 134** "I'm not really a group person, so it was challenging to listen to others" **POGIL Year 2** "Okay, I strongly agree that it should be used[41]" **Chemorganiser Year 1, p. 140** "It should be used from first semester I think[42]" **Chemorganiser Year 1, p. 140** "Yes, yes, use it again. We all agree" **Chemorganiser Year 2**	
Student Questionnaire Results "I would **recommend** that this approach used next year instead of the original way in which our tutorials were structured."	
Year 1 	Year 2 

5.6 ADDITIONAL FINDINGS AND IMPLICATIONS

5.6.1 OPPORTUNITY TO LEARN

Student behaviour: Absenteeism

Tutorial attendance was high in all groups before the implementation of the interventions, with more than 80% of students attending class regularly over both years of the study. Student attendance stayed constant for the Chemorganiser group over both years. In year 1, class attendance dwindled to 40% for the POGIL group by the end of the intervention; this had very serious implications for the study (see below). No increase in absenteeism was noted in the second year of POGIL implementation.

Students in the POGIL-experimental group begun to "vote with their feet" over the 4 week period of implementation in Year 1, solidifying their already vocalised discontent with this new intervention. Poor attendance of students in the tutorials means that students were not completely exposed to the POGIL intervention for the full duration, thus it could suggest their experience and perspective may be skewed. Not attending tutorials may also negatively affect the students' performance in the relevant study themes. Absenteeism created problems within the POGIL tutorials as group members were missing, increasing the workload on the remaining students. Such problems were not encountered in the second year. Students formed their own groups on a daily basis from class members present in the tutorials. Absenteeism did not increase.

5.6.2 TIME

Student Behaviour: Diligence/ Punctuality

In both years of study Chemorganiser students arrived at the venue on time and engaged quickly with the materials and prescribed work. During the first year of POGIL implementation, late-coming increasingly became a problem with students arriving up to 30 minutes late for a 50 or 100 minute session. Such student behaviour had severe implications on the implementation of POGIL as group members are assigned roles – if a particular group member is not present initially, they are considered absent, and the remaining students shoulder their responsibilities. When the member arrived late, roles had to be redistributed. In extreme cases, where all but one or two group members were present at the beginning of the tutorial, students had combined with other small groups – only to have their counterparts arrive much later, creating much disruption. In the second year of the study, this issue was completely avoided: POGIL students remained punctual, therefore roles were not affected.

Student Behaviour: Academic Preparation

In general, students from the Chemorganiser-experimental group said in focus group interviews that the amount of time they spent studying and on homework decreased. It was mentioned that students occasionally finished early which enabled them to begin homework during the tutorials. Such a finding implies that Chemorganisers were successfully used as tools which compact the load on the students, in both years.

Year 1 responses from the POGIL group in the focus group interviews varied: some students said it decreased the time they spent on homework and studies, some students felt the time required was unchanged and some students said it increased the time as they had to start from the beginning and re-teach themselves the work before attempting problems or studying.

It is expected that the time spent after hours on classwork will vary for each individual student, the variety of responses is acceptable. However, students spending time re-addressing complete sections in their own time is distressing. This is a time that should be spent on consolidating what has already been learnt. This finding was much milder in the second year of study.

Student Behaviour: Consultations

Students from the Chemorganiser-experimental group consulted frequently outside of the tutorial sessions, in both years. However, students from the POGIL-experimental did not consult at all in preparation for their common test. With the use of the Chemorganiser, students were able to realise they were experiencing difficulties and were sometimes able to pinpoint their areas of difficulty. The lack of consultations with students from the POGIL-experimental group may imply that the students could not identify their own areas of weakness. Another possibility was that students were over-confident in their understanding of the work (some POGIL students exhibited shock after writing the test and once scripts were handed back). These findings were similar in both years, however, not as pronounced in year 2 as POGIL students attained higher grades.

5.6.3 CLASSROOM DYNAMICS

Role of the Instructor

In the Chemorganiser-experimental group the instructor leads the class in a traditional way, however, the explicit nature of the Chemorganiser tool clarifies misconceptions and lessens the time spent in the tutorials on foundational principles. As such the load on the instructor was decreased. This was a refreshing and unexpected outcome, present in both years of the study: productive time usage increased in terms of teaching and learning time. It must be noted in both years that students had to be motivated by the instructor to engage with the Chemorganiser tool.

In the POGIL-experimental group, the aim is to have a student-centred approach, the instructor only acting as a guide and intervening when necessary. However, in the first year of the study, questions were asked from small groups continuously, ensuring the instructor was constantly engaged and often did not reach all the groups. If the facilitator decided to explain a general problem to the whole group, it was difficult to draw the attention away from group activities. It must be noted that in the second year of the study, it was far easier to draw students' attention and communicate with them as the venue used was the traditional style with fixed benches focused around the front of the classroom.

This finding points to a lack of confidence from the students in the concepts which they were guided to build. A possible reason may be nervousness due to the difference in teaching style. Another likely factor is psychological: students on the extended programme may be sensitive to failure and overly aware of gaps in their academic skills and as such constantly look for reassurance from the facilitator.

In both years the instructor had to act as the motivator, many students lacking intrinsic motivation when it came to group work, however, this was not as pronounced in the second year.

5.6.4 NATURE OF THE TASK

Length of task

The use of the Chemorganiser fitted neatly into the 50 minute timeslot. The POGIL-experimental group required roughly twice the time (a double time slot) to cover the same content. Often, small groups in the POGIL-experimental did not complete tasks even within the 100 minute time slot, however, this was not as pronounced in the second year.

The time required by POGIL is not catered for in the current chemistry curriculum design. Scheduling time outside of the tutorials is impossible as students of the extended programme have full timetables. Another complication is the fact that adding to contact time allocated to the module will increase the notional hours, which is not permissible.

Students may not be able to cope with the length of the POGIL worksheets from a time perspective or from a psychological perspective e.g. shut down when they feel overloaded. A possible reason for this challenge is that the language and wording may be too complex for second language speakers or for students who are still developing their academic literacy skills.

Facilities/Type of venue required

The use of Chemorganisers does not place demands on the venue. The POGIL approach requires students to work in small groups. Therefore, in the first year, a venue with free standing chairs and tables was required. Often such venues were in disarray, and the instructor had to rearrange the entire classroom set-up before students entered the venue. Such a situation was straining and time consuming for the instructor on a regular basis. The layout of the venue also increased the challenge when trying to get the students' attention or direct them to a solution given on the board because many students had to turn around to face the board then rotate again to engage with their group. This problem was overcome in the second year when traditional venues were used.

5.7 DISCUSSION OF FINDINGS IN TERMS OF RESEARCH QUESTIONS

5.7.1 How do the approaches influence student performance?

Student performance, in brief, was influenced by whether students experienced an intervention or not *and* by the nature of the intervention. In the first year of the study, the POGIL group under-performed when compared to the control and the Chemorganiser groups. In the following year, POGIL performance improved and there was no difference statistically between the POGIL group and the control group. Therefore student performance was influenced by the POGIL approach, however, the POGIL approach did not positively influence students' performance to a statistically noticeable extent as compared to the control group.

Returning to the first year of the study, the Chemorganiser group's performance was similar to that of the control group. After the second year of study, students who experienced the Chemorganiser approach performed significantly better than the control. Thus, the Chemorganiser approach may be viewed as positively influencing student performance. The narrower spread of performance around a higher mean for the Chemorganiser groups also suggests that the intervention is successful in uplifting the performance of most of the students, especially the weaker students. In literature, it was found that the Chemorganiser was most beneficial to weaker students (Reid, 2001; 2008), the majority of the students on the extended programme may be classified as weaker students and as such an improvement for what appears to be the entire experimental group is acceptable.

Given the shift in student performance from year 1 to year 2, for both interventions, it is proposed that the refined implementations of the interventions were successful. The researcher ventures the notion that by conducting minimal discussions in the Chemorganiser sessions students were allowed more time to engage with the task and practise using it, resulting in boosted performance. It is worth noting that the superior results reported for POGIL in other contexts (Farrel et al., 1999; Hanson, 2006) could not be repeated. Instead, the claimed outcome of a reduced gap between the performance of stronger and weak students upon the implementation of the Chemorganiser (Reid, 2001; 2008) was confirmed in this context.

There were limitations in the collection of quantitative data which was outside of the researcher's control: only ***redox reactions*** were assessed in Year 1 and the ***mole concept and stoichiometry*** in Year 2. This limitation may have influenced some of the findings, therefore, further work is necessary to confirm the generalisability of these findings

5.7.2 What are the impacts on the students' opportunity to learn within each approach?

This is perhaps the most difficult research question to answer as it consists of so many components (Section 2.5.3). The researcher proposes that student **engagement** is dependent on the emotional responses experienced. Emotional responses are triggered by both the nature of the task at hand and the required classroom dynamics (or prior experience thereof), as shown in the emergent model, Section 5.4. Emotional responses influence student behaviour, and in the case of opportunity to learn; **attendance, academic preparedness** and the **frequency of consultations** are of interest.

It is logical to assume that students who find themselves in a classroom environment in which they are either unhappy or uncomfortable will not participate or engage at optimum levels. In the first year of the study, only 10% of the students who experienced POGIL indicated that they were happy or comfortable with the on-going POGIL group work sessions. Classroom behaviour indicative of this emotional response was observed through withdrawal by weaker group members and increased frustration levels in stronger students.

Such levels of discomfort led to a steep decline in attendance noted by the instructor. A ripple effect of this was that 59% of the students did not feel prepared for assessment, responding "No, not at all" to the questionnaire item, "Do you feel adequately prepared for tests and exams?" A more puzzling finding was that even though the students did not feel prepared, they did not seek consultations with the instructor. Perhaps this academic behaviour suggests a lack of faith in the intervention transferred to the instructor? A contrary idea arises from observations from an external colleague, who referred to the students as being naive in terms of their own misunderstandings. The following quote from the focus group is also relevant, "in a group you are not sure whether you know something or not".

In the following year of the study, only 10% of the students who experienced POGIL indicated that they were unhappy or uncomfortable with the on-going POGIL group work sessions. Such a finding is in stark contrast to the previous year, indicating a dramatic shift in emotional responses from the students. In year 2, none of the students responded "No, not at all" to the questionnaire item, "Do you feel adequately prepared for tests and exams?" Student behaviour in terms of attendance was commendable; however, trends in consultations did not improve.

Upon analysis of variables of opportunity to learn for the Chemorganiser students, similar trends emerged over year 1 and year 2. Initially students were dubious, as expected when exposed to a new pedagogy and were inclined to paste the Chemorganiser hand-outs into their books or file them away out of sight. Students had to be encouraged by the instructor to make use of the Chemorganiser as a tool, but as soon as this was accomplished, each student began to blossom in terms of confidence and self-efficacy. Students appeared to look forward to the class, even cheering when they received a new Chemorganiser. The majority of students in both years, 79% in year 1 and 61% in year 2, indicated that they were happy or comfortable with the individual use of the Chemorganisers on an on-going basis. Students were content and trends in punctuality and attendance were continuously exemplary.

When returning to the concept of "preparedness", the majority of Chemorganiser students responded to the closed questionnaire item, "Do you feel adequately prepared for tests and exams?" with the statement "Partially, I will have to do a fair amount to preparation on my own." 71% of students selected this option in the first year, followed by 68% of students in the second year. Such a result may appear insubstantial at first glance, but it shows that the students acknowledge the role of the Chemorganiser as a tool, which only includes summaries and a structured framework, and do not see it as replacing the textbook or taught component of the course. Such a statement was confirmed by the students in the focus groups over both years of the study. Trends of frequent consultations are understandable in light of this well calibrated academic attitude. Students made full use of available consultations especially as the use of the Chemorganisers alerted them to areas of difficultly or steps within a calculation that they could not grasp or master on their own.

5.7.3 What influence does each *approach have on productivity, both inside and outside the classroom?*

To begin with, the researcher would like to make the distinction between time required to complete the task and productive time use during a task. From the onset, it was clear that POGIL worksheets would take more time to complete than a normal tutorial, and as such POGIL sessions were scheduled in double timeslots where possible. In the first year of the study, productivity was seen to rise for a short time then decreased rapidly, the decrease being accelerated by re-grouping of students. In the focus groups some students commented that they never adjusted to their "new" groups. The trend was noted by both the instructor and external observers. Much time was wasted at the beginning of a session before students engaged in the POGIL worksheets. Time on task was influenced by distractions or strained social dynamics. Productivity, in terms of learning, was further decreased when some groups attempted to subdivide the tasks instead of working together.

In the first year, 59% of POGIL students viewed their productivity as either very low or low when responding to the questionnaire statement "How much time was used productively during the tutorial?" It is clear that the students' opinion concurred with the observations of the educational practitioners. To add to this, focus group interviews revealed that homework and study time often increased due to the intervention.

The second year of the study showed a complete turnaround in terms of student opinion; 100% of POGIL students viewed their productivity levels as either high or very high when responding to the same questionnaire statement. Very few concerns regarding homework and study time were voiced by the students in the focus group interview. Increases in productivity were noted by both the instructor and external observers, however, students were sometimes still distracted (talking amongst their group which were likely friends), although this was seldom. The removal of the role of the reflector and presenter along with the formulation of the three new roles (see Section 4.4) increased the efficiency with which the groups worked.

The addition of time allocations also appeared to increase productivity during the intervention, although students had to be reminded not to obsess over these time allocations and thereby create distractions. During focus group interviews, some students commented that they found it "really fast" and that they had to rush slower members, due to the time allocations.

An interesting observation was that productivity came to a stand-still in the second year when students encountered complex, higher-order questions at the end of the POGIL worksheets. This may imply that cognitive overload was influential on productivity in the second year whereas in the first year, group dynamics prevented the students from even getting this far. Similar findings in terms of the cognitive load placed on students by complex questions is eluded to in literature by Gulacar et al. (2014, p. 964) "The complexities of the problems brought out the differences (in processing capacity), which were not clear while students were doing the simpler exercises".

In both years of the study, the majority of students who experienced the Chemorganisers viewed their class time as either productive or highly productive, 92% in year 1 and 84% in year 2. Students also commented that the Chemorganisers reduced homework time and provided effective summaries when studying. A small number of students withdrew when faced with a challenging worked example; however, most students took it in their stride.

5.7.4 How are the approaches received by the students?

Resistance to new pedagogy was expected for both interventions especially as they occur later in the academic year: an 'extreme' pedagogy may be more acceptable if students have no other frame of reference, especially if such an approach requires greater effort from students.

The attitudes of the majority of the POGIL students declined rapidly over the course of the intervention, this was noted by both the instructor and external observers in the first year of the study. The primary reason for this decline was group work and the associated social dynamics within prescribed heterogeneous groups. In the first year, 82% of students responded negatively (either disagreed of strongly disagreed) with the questionnaire statement, "I would **recommend** that this approach used next year instead of the original way in which our tutorials were structured" after experiencing the intervention. When comparing this finding to literature Fig. 2 Section 2.2,5, shows that 80% of students responded positively to a very similar statement: the dissimilarity between expected student enjoyment and actual student enjoyment was one of the primary motivators of change within the study and the incorporation of action research (see Chapter 4).

Perceptions radically altered in the second year of the study, with 79% of students responding positively (either agree or strongly agree) to the very same statement. Such findings were confirmed, by both the instructor and external observers. The researcher proposes that the main reason for such a shift in attitude is the altered grouping structure: students were able to choose their own groups. The significance of the alteration is that most groups became homogeneous in terms of academic achievement, the benefits of which are given in the literature, Section 2.2.2. Cultural and gender similarities were also noted in the groups, however, the groups could not be strictly classified as uniform on either of the latter two variables.

Observed attitudes to the Chemorganiser were positive and encouraging over both years of the study. Over 80% of students in the first year and over 70% of students in the second year responded positively (either agree or strongly agree) to the statement, "I would **recommend** that this approach used next year instead of the original way in which our tutorials were structured". The researcher postulates that the slight decrease in overwhelming positivity may be due to including slightly more challenging questions to the Chemorganisers in the second year and requiring the students to engage with the tools more independently.

5.8 REFLECTIONS ON THE SUITABILITY OF POGIL

POGIL results within the first year of the study may be viewed as poor all round. Such results were unanticipated by the researcher. In an attempt to explain these findings, the following points are raised in hindsight and are discussed with the aid of literature. Overall the specific context of this study is that of under-prepared students in the first year of an extended programme degree, many of whom are conscious of unfair stigma attached to such a programme. This specific context appeared to have the greatest influence on the suitability of POGIL.

Reasons why POGIL did not work as planned:

1. The influence of group work
   - What the researcher refers to as the 'masking' influence of group work will hereby be explored. The nature of group work is such that students often appear to be gaining in knowledge and ability when in fact they are not. If the group appears to be functioning well; the learner, group members and instructor assume that meaningful learning has occurred for all and that this will translate into pleasing student performance in assessment. Thus the masking effect is simply the lack of awareness of individual learning. Wilkinson (1990) noted that under certain circumstances, low-ability students seem to learn higher-than-expected levels after placement in small, heterogeneous ability groups. The findings were similar in this study: initially all students appeared to be learning productively, it was only with time and the confirmation of assessment that it was seen that majority of the students were not coping when assigned to heterogeneous groups in the first year. This was true for all students, not just the low ability students.
   - It is postulated that the heterogeneous grouping structure was one of the main reasons why POGIL did not work in a setting in which most of the students could be considered academically under-prepared. "Indeed, heterogeneous groups may serve to maintain the status quo among students and consequently deny those of low ability opportunities to engage in the rich verbal interactions crucial for learning, unless teachers intervene to alter the group's processes of interaction" Wilkinson and Silliman (2001, Peer Learning in the Classroom, para. 5).

- Within heterogeneous groups it has also been found that "low-ability students had fewer opportunities to demonstrate to other group members what they did know, and thus had fewer opportunities to receive feedback on the adequacy of their knowledge" (Wilkinson, 1990, p. 213). This was confirmed in focus group interviews when students commented that they could not differentiate between what the group had learnt and whether they had learnt anything.
- Often fear of exposure inhibits certain group members from fully participating in group work; some studies indicate that women and minority students were marginalised (Camacho and Lord, 2011; Piller and Pavlenko, 2008). However, in this study the academically weaker students marginalised themselves through fear of having their short-comings exposed or by slowing the group and causing frustration. Such an action is classified as self-protection – whether conscious or not.

2. Cognitive Overload
    - The structure of a POGIL worksheet consisted of information being presented initially, either in the form of a table, graph or condensed paragraph, which students had to use to create concepts together. Students must first fully grasp the information before they can begin to process it. This did not always occur in the POGIL classroom, especially as the questions became more complex: "One example of ineffective instruction occurs if learners unnecessarily are required to mentally integrate disparate sources of mutually referring information such as separate text and diagrams. Such split-source information may generate a heavy cognitive load, because material must be mentally integrated before learning can commence" (Chandler and Sweller, 1991, p. 293).
    - POGIL worksheets were observed to be lengthy and 'text-heavy' by the instructor and external observers. Strain on cognitive processing capacity is often caused by limited language skills, and in this study, most students are second language English speakers: "Attention is misdirected, and cognitive resources are devoted to an activity that, although an essential precursor to learning, is itself unrelated to learning. If cognitive effort is devoted to activities other than learning, we might expect interference with learning" (Chandler and Sweller, 1991, p. 295). That is, the brain must work harder to process language while simultaneously trying to integrate new information. Carroll (1989) highlights the ability to understand instruction as a main influential factor on the effectiveness of the instruction. A study by Johnstone and Selepeng (2000) asserted that second language speakers will devote up to 20% of their processing capacity to mental

translation, as not only English translations apply but also complex scientific terminology.

3. Associations with pedagogy
   - Student perceptions are strongly influenced by prior experiences. Most students were exposed to group work at high school, although not in the same format as POGIL, but the associations in terms of emotional responses still remain (see Section 5.4). An example of such emotional responses include the idea that the group work will be unproductive, students dread "slackers" who piggy-back on others.
   - Such pedagogy, as required in POGIL, requires a specific type of thinking process and strong problem solving skills which the students are not guaranteed to possess given their schooling background. “The process (of inquiry learning) must begin in kindergarten, and continue with age-appropriate challenges, at each grade level.” (Alberts, 2000).
   - Resistance to a new pedagogy is expected. The researcher ventures that high levels of resistance and dislike were experienced as students were placed in a situation out of their comfort zones, both social and academic. Such a situation required the students to put in more effort than what they were used to which detracted from the productive time on task.

5.9 SYNTHESIS

Chapter 5 began with a presentation of student performance both pre and post intervention for each year of the study. In the first year of the study performance was poor in general indicating that the assessment tool was either over-pitched and/or that students find redox reactions challenging. The Chemorganiser group performed the best on average, with the POGIL group performing significantly lower than both the Chemorganisers and the control groups. The refinements in terms of action research as described in Chapter 4 were fruitful: the POGIL intervention improved noticeably in the second year in the four criteria associated with effectiveness in this study. Several ideas were postulated as to why POGIL was not as effective as it has been elsewhere, including sensitive group dynamics, negative associations with group work held by the students and the high level of cognitive demand placed on the students by learning activities such as POGIL.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

This is the final chapter of a two year study, in which the researcher seeks to draw meaningful closing conclusions which may pave the way to further research. The chapter begins with a brief overview of the structure of the study and the motivations behind such a structure. Next, conclusions are drawn from Section 5.6 and related to the ultimate question of instructional effectiveness, in Section 6.3. Before proceeding with the rest of the chapter, the researcher breaks to give personal reflections on the journey of the study, which should add value and perspective to the closing sections.

6.2 OVERVIEW OF THE STUDY

This study began as a mixed methods study to determine the effectiveness of each approach, POGIL or the Chemorganiser, within the specific setting of first year South African extended programme chemistry students. The researcher initially sought to gather data from a variety of sources to improve the quality and trustworthiness of any findings or conclusions. The study was planned over two years, to ensure that the findings were reproducible and not specific to a particular group of students. However, the gravity of the findings at the end of the first year of the study precipitated a journey into action research which aimed mainly at improving the effectiveness of the POGIL approach through modifications to the implementation thereof.

The second year of the study proved far more fruitful in terms of effectiveness for POGIL. The findings from the Chemorganiser implementation remained fairly constant, indicating a reproducibility of findings and an assurance of the robust nature of the intervention for the researcher or any other interested parties.

6.3 SUMMARY OF THE FINDINGS IN TERMS OF EFFECTIVENESS

To begin with, the findings of the second year of the study (post refinement) are the most applicable for this summary of effectiveness. When exploring the question of productivity, students in both groups appeared productive, that is the interventions were successful in stimulating productivity in the classroom. The trend in student opinions of preparedness for assessment were almost identical in year 2 (see Table 10), that is both interventions were viewed as equally adequate in the preparation they provided for assessment. The final construct of student preference did reveal that POGIL students were less positive about recommending this approach for the next year (40% were neutral in Table 12 as compared to only 13% of the Chemorganiser group).

As with the majority of models dealing with the effectiveness of schooling or instruction, the measurable output is the student achievement. This study has adhered to this premise (Section 2.5.3 and 4.5) and sought to measure student performance whilst exploring classroom variables that may ultimately impact on performance. Overall effectiveness, in which the two interventions are in competition, is not the only goal of this study but strategies of improving the effectiveness are just as valuable as they may even outlast current judgements.

When comparing POGIL and the Chemorganiser approach, it is clear that the Chemorganiser was a more effective method of instruction as student performance benefitted the most. However, from year one to year two, through modifications, effectiveness as measured by the POGIL student performance was improved to be on par with that of the control group. This is a substantial finding and proves that instructional effectiveness in terms of this study can be manipulated through various classroom level variables.

Links between the qualitative variables and the quantitative output of student performance are portrayed in both the conceptual framework (Section 2.5.3) and the model of emergent themes (Section 5.4). The researcher aims to tentatively evaluate the strength of these links or associations in hindsight using these constructs. The observed powers of the associations have been intuitively compiled by the researcher and are tabulated on the following page as strong, moderate or weak associations. Please note that the following table is a summary, not based on statistical analysis but on the researcher's own conclusions. It is posited that a strong association of a variable to increased student performance indicates the prominence or influence of the variable on overall instructional effectiveness.

Table 13. Association of classroom variables with student performance.

Variable	Association with Effectiveness as reflected by performance
Opportunity to learn – engagement (emotional response)	Strong Students who withdrew or did not fully engage in the intervention did not appear to perform as well as their counterparts
Opportunity to learn – attendance (student behaviour)	Strong Trends in class attendance were strongly tied to student performance
Time – productive use of time on task (student behaviour)	Strong Student efforts at productivity resulted in high performance. Giving way to distractions decreased learning and engagement visibly
Time – required time on task (nature of task)	Weak Time required by the task is not as important as how well time is utilised by the students in the class
Time – time required outside of the classroom for homework and studying (academic attitude)	Weak – Moderate This variable was highly dependent on the individual characteristics of the student, and thus difficult to gauge.
Preference – social comfort/ ease	Strong Whenever students were uncomfortable their behaviour deviated from the optimum, decreasing learning
Preference – sense of self-efficacy	Moderate - Strong A feeling of confidence empowered and motivated students to further engage and perform at higher levels

In conclusion, many variables affect instructional effectiveness, to greater and lesser extents, but this does not discount the value of exploring such variables. The researcher maintains that a holistic view was essential in this study and therefore all variables still have merit.

6.4 REFLECTIONS OF THE RESEARCHER

As an educator, the needs of my students and the desire to ascertain the best possible practice inspired my research and created an opportunity to further my education. Both approaches were selected to benefit my students; I was hopeful and excited at the onset of the research and strove to deliver the implementations to the best of my abilities. This was also an exciting time for my students as they felt they could make a meaningful contribution to my education.

I was very pleased with both interventions initially, and shared my findings where I could. I felt proud of my students and our success, especially when my colleagues observed the session and showed interest in adopting the two approaches themselves. However, the POGIL intervention began to pull in a more negative direction. At first I was concerned and hoped the re-shuffling of students would solve all the problems I was facing, but it did not, it worsened the situation. I felt uncomfortable for exposing my students to a way of teaching which they obviously disliked intensely. It was embarrassing for colleagues to observe such sessions.

At the end of the first year I was against exposing the following year's students to the POGIL intervention. I knew that my findings were not a fluke and I did not need to repeat the intervention and potentially damage another batch of students to prove this. It was my initial feeling to abandon POGIL and do an in-depth study of the Chemorganiser over more topics in the second year of the study, with all my students. It was a great struggle on my behalf to embrace the idea of action research to modify POGIL, as I had already discounted its worth for my students. With time, and much discussion with my supervisor, I came round to the idea and applied myself to creating modifications that would create a brighter outcome for any student undergoing the POGIL intervention in year 2.

I was greatly relieved by the results of year 2, as I observed the re-implementation of POGIL. The modifications proved worthwhile! I am grateful that I had the opportunity to attempt POGIL again and that my perceptions were altered – my colleagues were also pleasantly surprised. However, I would strongly recommend the full-scale implementation of the Chemorganiser in foundation chemistry as the Chemorganisers were easier for me to use as an educator (the demands on my explanation time were decreased and no specific space or venue was required). Chemorganisers were more applicable for my students, especially in terms of confidence building.

6.5 EDUCATIONAL IMPLICATIONS OF THE FINDINGS

Two principle implications have emerged when dealing with students, the majority of whom are 'weak' or academically under-prepared: such students are easily influenced by social circumstances precipitated by group work and, secondly, the instructor should be mindful of the cognitive processing capacity of the students when selecting pedagogies or instructional materials.

Group work requires social interactions for the good of the student and the common good of the group itself. Within a situation where students lack confidence in their abilities, and do not want to be exposed to the group, the group cannot function productively. It has been noted that withdrawal is amplified in situations in which such a student is grouped with individuals with whom they do not normally socialise. A group that cannot function properly is a frustration to all those involved and becomes more so with time. Such was the case in this study there was a delicate balance between student engagement and productivity, and students' sense of vulnerability or other challenging social factors such as gender, culture and socio-economic status.

Overall, such findings caution that instructional design should be sensitive to cultural and contextual factors, especially when dealing with group work as there is a complex interplay of variables which will influence the effectiveness. An implication of this finding is that novel instructional designs should always be carefully tested before full scale implementation.

Returning to the second fore mentioned educational implication, the cognitive processing capacity of the student, the following statement by Piaget (2003, p. S12; 1964), is pertinent: "To receive information he (the student) must have a structure which enables him to assimilate this information". That is, the student must have cognitive structures or the "cognitive architecture" which will enable understanding. Often low ability students have a lower conceptual understanding and a disjoint knowledge structure, that is they may have the same cognitive capacity but the processes which take place within the working memory are limited by poorly formed or non-existent schema (Gulacar et al., 2014, p. 966).

Johnstone (1997, p. 264) defines learning as the reconstruction of knowledge, not the transmission of it. This promotes the notion that the scaffolding offered by a Chemorganiser may be highly beneficial to students as it will align thoughts and ideas, and thus, minimise the occurrence of misconceptions. For new knowledge to be meaningful it must be integrated into a branched learning system (Johnstone, 1997, p. 265), which weak students may not have or have correctly, therefore the structure and scaffolding of the Chemorganiser is one of its main benefits in this case.

6.6 CONTRIBUTIONS AND SIGNIFICANCE OF THE STUDY

The findings of this study may not be used to make generalised statements as to the suitability and effectiveness of either POGIL or the Chemorganiser. Despite this, the researcher has strived to maintain the quality and integrity of the qualitative data and the rigour of the quantitative data throughout the study. The study is still of significance to the researcher and colleagues working in the same extended programme environment and may inform future educational decisions.

The chosen pragmatic paradigm enabled the study to embrace findings that would traditionally have been mutually exclusive. Thus richer, more trustworthy findings and conclusions could be made. The use of mixed methods research was considered successful in this study and is advocated for other studies in education, as the significance may be respected by researchers of both positivist and constructivist paradigms. Such a stance also accommodated and supported the use of action research within this study, which also improved the quality and implications of the study.

This study has aimed to add a contextual understanding of the implementation of different educational innovations in an African extended programme background. It has also sought to refine a framework of effectiveness which other educators can use to evaluate their own classroom practices. Via these two means the study has expectantly added data to a pool to be used and enriched by all fellow educators, "Professional educators always want their instructional decisions to be based on the best possible data" (Sagor, 2000).

6.7 AREAS FOR FURTHER RESEARCH

The following areas for further research are proposed by the researcher:

1. Further quantitative research on the impacts of each intervention, POGIL and the Chemorganiser, on student performance in different chemistry themes on the extended programme. Due to circumstances outside of the researcher's control, performance data pertaining to ***redox reactions*** was collected in the first year of the study and performance data for the ***mole concept and stoichiometry*** was collected in the second year. This is a weakness of this study which would be addressed by further research.
2. The investigation of which approach, POGIL or the Chemorganiser, would hold greater long-term benefits for the students in terms of both information retention and conceptual understanding (even if factual information is not retained, does the schema for understanding the mole, for example, persist in the student's long-term memory).
3. To explore the limits of the effectiveness of each approach in terms of academic maturity. For example, Chemorganisers were proved to be effective in the first year of an extended programme; how far into a student's academic career would such a tool be effective before it became unnecessary? Would the effectiveness of POGIL increase with academic maturity and exposure to the scientific method?
4. Examining whether students are able to translate the tools of such a pedagogy into their own learning strategies. Could students effectively harness the layout and schema behind the Chemorganiser to create their own similar tools in other topics or even other subjects, and would these be effective?
5. Another opportunity would include the larger scale concurrent comparison of the two approaches using a mainstream first year sample and an extended programme sample. This would contribute an understanding of any differences required in pedagogical approaches. However, this would take a large amount of human resources and as such may add an

element of unreliability to the results as no two people have exactly the same style of teaching and as such may influence the implementation of approaches.

6.8 CONCLUDING REMARKS

In closing this study, the researcher would like to make the proposition of full-scale implementation of the Chemorganisers for the extended programme chemistry courses. This would be a large undertaking as some resources would have to be constructed from scratch, however, the long term student benefits would justify such an undertaking.

It is the opinion of the researcher and the students that similar materials would be extremely helpful in other courses. The construction and implementation of "Physicsorganisers", "Bio-organisers" and "Mathorganisers" would enhance the extended learning environment by allowing for solid foundations to be built, along with building up realistic confidence or self-efficacy within the students.

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APPENDIX A

STUDENT INFORMATIVE LETTER

Dear First Year BSc Student

I am currently busy with an MSc in Science Education. The aim of my research is to explore two different teaching methods during two themes in the scheduled CMY 143 tutorials. The content covered using the new methods will be the identical to the content stipulated in the course.

In order for me to do this research I will need to observe you while participating in class activities and analyse the results you achieve with the different teaching methods. I ***may*** also need to ask you questions (either during a voice recorded interview or through a questionnaire) about how you experienced methods.

If you agree to fully participate in this study, you will remain anonymous and you will be rewarded appropriately at the end.

Thank you for your cooperation
Kind regards

Christine Mundy
MSc Student
University of Pretoria

STUDENT CONSENT FORM

I understand that:

- The aim of the study is to explore two different teaching methods during the scheduled CMY 143 tutorials
- I am required to participate in class activities and use study resources to the best of my abilities
- I ***may*** be required to participate in an interview
- I will be required to complete a 10 minute questionnaire at the end of the study
- Any personal information about me that is collected as part of this study will be held in the strictest confidence and will not form part of my permanent record at the University of Pretoria.
- I am not waiving any human or legal rights by agreeing to participate in this study
- I am over 18 years of age and my participation is voluntary

Signature ____________________ Date________________

Student Number ____________________

INFORMATIVE LETTER TO RELEVANT AUTHORITY

Dear CMY 143 Course Coordinator

I am currently busy with an MSc in Science Education. The aim of my research is to explore two different teaching methods during the scheduled CMY 143 tutorials. With your permission I would like to implement the teaching methods during the themes of **the mole concept, stoichiometry** and **redox reactions**. The content covered will be the identical to the content stipulated in the course. I do not believe the interventions will disadvantage the students in any way.

Thank you for your cooperation
Kind regards

Christine Mundy
MSc Student
University of Pretoria

RELEVANT AUTHORITY CONSENT FORM

I , _________________________, the designated CMY 143 Course Coordinator, hereby give permission to the researcher to conduct the study using CMY 143 students during the themes of **the mole concept, stoichiometry** and **redox reactions**. I understand that the students will not be disadvantaged in any way.

Signature ____________________ Date_________________

PROPOSED FOCUS GROUP AND QUESTIONNAIRE ITEMS

INTERVIEW ITINERARY

Opportunity to learn

1. **Do you understand what is expected of you during tutorial sessions?** *(Adapted from Class evaluation Form, Derek Bok Centre for Teaching and Learning, Harvard University, Form 4)*

2. **Comment on how you experienced the pace of the tutorials (i.e. how much was covered per session)?** *(Adapted from Teaching Improvement Form – Discussion Courses, Carnegie Mellon University Eberly for Teaching Excellence)*

3. **What are your views on the POGIL activities that you participated in (i.e. worksheets completed through group work)?** *(Adapted from Teaching Improvement Form – Discussion Courses, Carnegie Mellon University Eberly for Teaching Excellence)*
   Design (of the worksheet)?
   Organisation (of the group)?
   Comfort (in the group)?
   Comment on the dynamics of group work
   Did you feel that this material supplied you with sufficient opportunities to learn?

4. **What are your views on the use of the Chemorganiser (i.e. explanation in class and usefulness as a learning tool/aid)?** *(Adapted from Teaching Improvement Form – Discussion Courses, Carnegie Mellon University Eberly for Teaching Excellence)*
   Design (the layout of the Chemorganiser)?
   Organisation (of concepts by the Chemorganiser)?
   Comfort (with using the material)?
   Did you feel that the use of this material supplied you with sufficient opportunities to learn?

5. **Comment on the amount of effort and involvement required from you during these tutorial sessions.** *(Adapted from Student Instructional Report II, Educational Testing Service)*

Time used in each Educational design

6. **Outside of tutorials, how much time do you spend on homework?** *(Adapted from Class evaluation Form, Derek Bok Centre for Teaching and Learning, Harvard University, Form 4)*

7. **Is this amount of homework time in line with the rest of the themes in the course?**

8. **Did the use of this educational design influence your study time for this section?**

Preference in Educational design

9. **Do you feel that the design of this educational material contributed to your learning?** *(Adapted from Student Instructional Report II, Educational Testing Service)*

10. **Would you recommend this type of educational design be used again (next year)?** *(Adapted from Moog et al, 2009, p. 98)*

Student comments and opinions welcome, this is a semi-flexible interview

Resources referenced in items 1, 2, 3, 4, 5, 6 and 9 can be found in the following book:

Fox, M. A., & Hackerman, N. (Eds.). (2002). *Evaluating and improving undergraduate teaching in science, technology, engineering, and mathematics*. National Academies Press.

ACCEPTANCE OF ETHICS COMMITTEE

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

ETHICS COMMITTEE

Faculty of Natural and Agricultural Sciences

18 June 2013

Prof M Potgieter
Department of Chemistry
University of Pretoria
Pretoria
0002

Dear Prof Potgieter

EC130528-050: Exploring two possible education innovations in first year extended program chemistry

This protocol conforms to the requirements of the NAS Ethics Committee.

Kind regards

Prof NH Casey
Chairman: Ethics Committee

Agriculture Building 10-20
University of Pretoria
Private bag X20, Hatfield 0028
Republic of South Africa

Tel: 012 420 4107
Fax: 012 420 3290

ethics.nas@up.ac.za

Manager: ____________________________

Recorder: ____________________________

APPENDIX B

POGIL RESOURCES

Rules for Balancing Half-reactions

(net ionic equations, acidic or basic solutions)

Model 1: Balancing a half-reaction in acidic medim

Illustrated for reduction of sodium dichromate ($Na_2Cr_2O_7$) to chromium(III) ions in acidic solution. All ions may be safely assumed to be in acidic aqueous solution unless otherwise stated.

Start by writing unbalanced equation from known info.	
Assume that soluble ionic species will dissolve, and ignore spectator ions (in example: Na + is spectator ion)	
Assign oxidation numbers to element that is oxidized or **reduced** (in this case)	
Balance elements except O and H	
Balance the O by adding H_2O to the side that has too few O.	
Balance the H by adding H_2O to the side that has too few O.	

Exercises

1 min

1. What does the arrow represent in a chemical reaction?

   ____

1½ min

2. For reaction 1, how many H atoms, Cu atoms, and O atoms are represented on:
   a. The reactant side?

      ____

   b. The product side?

      ____

1½ min

3. For reaction 2, how many C atoms and O atoms are represented on:
   a. The reactant side?

      ____

   b. The product side?

      ____

1 min

4. Based on your answers to CTQs 3 and 4, what general statement can be made about the number of atoms of each type on the two sides of a chemical equation?

   ____

   ____

Information

Atoms are neither created nor destroyed when chemical reactions take place. Therefore, the number of atoms of each element must be identical on the reactant (left) and product (right) sides of a balanced chemical reaction. Such a chemical equation is said to be **atom balanced**.

Model 2: Four Balanced Chemical Reactions

In each of the balanced chemical reactions given below, the symbol "*(aq)*" indicates that the molecule or ion is surrounded by water molecules.

$Ag^{+}(aq) + Cl^{-}(aq) \rightarrow AgCl(s)$ ③

$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$ ④

$3\ ClO^{-}(aq) \rightarrow 2Cl^{-}(aq) + ClO_3^{-}(aq)$ ⑤

$2\ Cr^{2+}(aq) + Mg^{2+}(aq) \rightarrow 2Cr^{3+}(aq) + Mg(s)$ ⑥

Critical Thinking Questions

3 mins

5. Confirm that each of the chemical equations in Model 2 are *atom balanced.*
6. a) For each of the chemical equations in Model 2, determine the sum of the charges on the left-hand side and the sum of the charges on the right-hand side.

3 mins

   b) Based on the reactions in Model 2, which, if any, of the following statements are correct?

      i. The sum of the charges on both sides of a chemical equation must equal zero.
      ii. The sum of the charges on both sides of a chemical equation must be a positive number.
      iii. The sum of the charges on both sides of a chemical equation must be a negative number.

1 min

7. What general statement can be made about the sum of the charges on both sides of a balanced chemical reaction?

____

____

Information

Protons and electrons are neither created nor destroyed when chemical reactions take place. Therefore, the total charge must be identical on the reactant and product sides of a balanced chemical reaction. Such a chemical equation is said to be **charge balanced**.

Exercises

1. Balance these chemical reactions:
   a) $Cr(s) + S_8(s) \rightarrow Cr_2S_3(s)$

   b) $NaHCO_3(s) \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(g)$

   c) $Fe_2S_3(s) + HCl(g) \rightarrow FeCl_3(s) + H_2S(g)$

   d) $CS_2(\ell) + NH_3(g) \rightarrow H_2S(g) + NH_4SCN(s)$

2. Write a chemical equation for the gaseous reaction of methane (CH_4) with oxygen (O_2) to form carbon dioxide (CO_2) and water (H_2O).
3. Write a chemical equation that forms one mole of glycine, $H_2NCH_2COOH(s)$, from solid carbon, gaseous oxygen, gaseous nitrogen, and gaseous hydrogen.
4. Which of the following chemical equations are not balanced?
   a) $NO_2^-(aq) + ClO_2^-(aq) \rightarrow NO_3^-(aq) + Cl^-(aq)$
   b) $NO_2^-(aq) + ClO^-(aq) \rightarrow NO_3^-(aq) + Cl^-(aq)$
   c) $Cr(s) + Pb^{2+}(aq) \rightarrow Pb(s) + Cr^{3+}(aq)$
   d) $H^+(aq) + SO_3^{2-}(aq) \rightarrow HSO_3^-(aq)$
   e) $4AgBr(s) + 4OH^-(aq) \rightarrow O_2(g) + 2H_2O(\ell) + 4Ag(s) + 4Br^-(aq)$

Model 3: The Balanced Chemical Reaction.

A balanced chemical reaction can be interpreted in two ways. First, it can be thought of as describing how many molecules of reactants are consumed in order to produce a certain number of molecules of products. Analogously, it can be thought of as describing how many *moles* of reactants are consumed in order to produce the indicated number of *moles* of products.

$$CuO(s) + H_2(g) \rightarrow Cu(s) + H_2O(g) \quad (1)$$

$$2\ CO(g) + O_2(g) \rightarrow 2\ CO_2(g) \quad (2)$$

Critical Thinking Questions

30 sec

8. How many H_2O molecules are produced for every H_2 molecule that is consumed in reaction 1?

____

2 mins

9. For reaction 2:
   a. How many CO_2 molecules are produced for every O_2 molecule consumed?

   ____

   b. How many CO_2 molecules are produced for every CO molecule consumed?

   ____

   c. How many molecules of CO_2 are produced when 2 molecules of O_2 are consumed?

   ____

   d. How many moles of CO_2 are produced when 5 moles of O_2 are consumed?

   ____

30 sec

10. How many moles of CuO react in order to produce 12 moles of Cu in reaction 1?

____

1 min

11. Determine the total number of reactant molecules and the number of product molecules for reaction 1 and reaction 2.

____

____

1 min

12.
   a. Is the number of molecules identical on the reactant and product sides of these balanced reactions?

   ____

   b. Does the total number of moles of gas increase, decrease, or remain constant when reaction 2 occurs?

   ____

3 mins

13. Explain how your answers to CTQ 13 can be consistent with the idea that atoms are neither created nor destroyed when chemical reactions take place.

____

____

____

3 mins

14. Is it correct to state that if 100 grams of CuO are consumed when reaction 1 occurs, then 100 g of Cu are formed in the process? Why or why not?

____

____

____

3 mins

15. Describe, using grammatically correct English sentences, the steps taken to calculate the number of grams of CO_2 produced in reaction 2 given that X grams of O_2, are consumed.

____

____

____

Exercises (use conversion factors)

5. How many grams of Cr_2S_3 are produced when the reaction in Ex. 1 a (above) occurs with 10.0 grams of chromium being consumed?
6. How many grams of hydrogen sulfide are produced when 0.0365 grams of carbon disulfide are consumed in the reaction in Ex. 1 d?
7. How many grams of iron (III) chloride are produced when 26 grams of hydrogen sulfide gas are produced in the reaction in Ex. 1 c?
8. The thermite reaction has been used for welding railroad rails, in incendiary bombs and to ignite solid-fuel rockets. The reaction is

$$Fe_2O_3(s) + 2Al(s) \rightarrow 2Fe(\ell) + Al_2O_3(s)$$

What masses of iron (III) oxide and aluminium must be used to produce 15.0 g of iron? What is the mass of aluminium oxide that would be produced?

9. Nitrogen (N_2) combines with hydrogen (H_2) to form ammonia (NH_3). How many grams of ammonia are formed when 145 grams of nitrogen are consumed by hydrogen?
10. Indicate whether the following statement is true or false and explain your reasoning.

    When carbon monoxide gas reacts with oxygen gas to form carbon dioxide gas, the number of gas molecules present decreases.

Problems

1. Nickel can react with gaseous carbon monoxide to form $Ni(CO)_4$. Other metals present do not react. If 94.2 grams of a mixture of metals reacts with carbon monoxide to produce 98.4 grams of $Ni(CO)_4$, what is the mass percent of nickel in the original sample?
2. a) A 1.000 g sample of iron reacts with element "Q" to form 1.430 g of Fe_2Q_3. Determine the identity of element "Q".

   b) Write a chemical equation for this reaction.

Manager: ______________________________

Recorder: ______________________________

Time keeper: ____________________________

ChemActivity 28, pp. 160-162

The Mole Concept

Model: The Elephant and the Methane Molecule

One elephant has one trunk and four legs.

One methane molecule, CH_4, contains one carbon atom and four hydrogen atoms.

$$1u = 1.661 \times 10^{-24} g$$

1 dozen = 12 items

1 mole = 6.022×10^{23} items = Avogadro's Number

1 mole ≠ 1 molecule

Critical Thinking Questions

Use the <u>conversion factor method</u> for Q 1 – 10

Time keeper, please note: Each CTQ (critical thinking question) should take 3 minutes to complete.

1. How many trunks are found in one dozen elephants? Give your answer in terms of a number (such as 17 or 3.25×10^{15} trunks).

____

____

____

____

2. How many legs are found in one dozen elephants? Give your answer in terms of a number (such as 11 or 3.25×10^{15} legs).

____

____

____

____

3. How many carbon atoms are found in one dozen methane, CH_4, molecules? Give your answer in terms of a number (such as 17 or 3.25×10^{15} C atoms).

____

____

4. How many hydrogen atoms are found in one dozen methane molecules? Give your answer in terms of a number (such as 17 or 3.25×10^{15} H atoms).

5. How many trunks are found in one mole of elephants?

6. How many legs are found in one mole of elephants?

7. How many carbon atoms are found in one mole of methane molecules?

8. How many hydrogen atoms are found in one mole of methane molecules?

9. Calculate the average mass (in u) of one methane molecule. Your answer should have 2 decimal places.

____

____

____

____

10. Based on your answer to CTQ 9, calculate the mass (in grams) of one mole of methane molecules.

    ____

    ____

    ____

    ____

11. Use a grammatically correct English sentence to describe how the mass in u of one molecule of a compound is related to the mass in grams of one mole of that compound.

    ____

    ____

    ____

    ____

Exercises (to be done in your own time or as homework)

Unless otherwise stated, calculate all mass values in grams.

1. What is the mass of 1.00 mole of Cu?
2. What is the mass of 1.00 mole of sodium(I)fluoride, NaF?
3. Consider a 1.00 carat diamond (pure C) that has a mass of 0.200 grams. How many carbon atoms are present in this diamond? Give your answer in terms of a number (such as 17 or 3.25 X 10^{15} C atoms) and as a number of moles of C atoms.
4. Consider 1.00 mole of dihydrogen gas, H_2. How many dihydrogen molecules are present? How many hydrogen atoms are present? What is the mass of this sample?
5. Ethanol has a molecular formula of CH_3CH_2OH. What is the mass of 1.000 moles of ethanol? What is the average mass of one molecule of ethanol?
6. What is the mass of 0.5623 moles of ethanol, CH_3CH_2OH?
7. a. How many moles of ethanol are present in a 100.0g sample of ethanol?
   b. How many moles of each element (C, H, O) are present in a 100.0g sample of ethanol?

   c. How many grams of each element (C, H, O) are present in a 100.0g sample of ethanol?
8. How many moles of carbon dioxide, CO_2, are present in a sample of carbon dioxide with a mass of 254 grams?
9. How many moles of O atoms are present in a 254 g sample of carbon dioxide
10. How many carbon atoms are found in 0.500 g of glycine, H_2NCH_2COOH?
11. Indicate whether each of the following statements is true or false, and explain your reasoning.
    a. One mole of NH_3 weighs more than one mole of H_20.
    b. There are more carbon atoms in 48 grams of CO_2 than in 12 grams of diamond (a pure form of carbon).
    c. There are equal numbers of nitrogen atoms in one mole of NH_3 and one mole of $N_{2.}$
    d. The number of Cu atoms in 100 grams of Cu(s) is the same as the number of Cu atoms in 100g of copper(II)oxide, CuO.
    e. The number of Ni atoms in 100 moles of Ni(s) is the same as the number of Ni atoms in 100 mole of nickel(II)chloride, $NiCl_2$.
    f. There are more hydrogen atoms in 2 moles of NH_3 than in 2 moles of CH_4.
12. Use grammatically correct English sentences to describe how to calculate the number of H atoms in “z” moles of $NH_{3.}$

Time keeper, please note: 32 minutes are allocated for the CTQs.

Complete CTQ before proceeding with questions marked with a ☆

Manager: ______________________________

Recorder: ______________________________

General Secretary: ______________________

Limiting Reagent

(How Much Can You Make?)

Model 1: The S'more

A delicious treat known as a S'more is constructed with the following ingredients and amounts:

1 marie biscuit
1 mini chocolate bar
2 marshmallows

At a particular store, these ingredients can be obtained only in full boxes, each of which contains one gross of items. A gross is a specific number of items, analogous (but not equal) to one dozen dozen (12 × 12 = 144 items). The boxes of items have the following net weights (the weight of the material inside the box):

Box of marie biscuits	9.0 kg
Box of chocolates	36.0 kg
Box of mashmallows	3.0 kg

Critical Thinking Questions

1½ min

1. If you have a collection of 100 marie biscuits, how many chocolate bars and how many marshmallows do you need to make S'mores with all of the marie biscuits?

____

____

____

4 min

2. If you have a collection of 1000 marie biscuits, 800 chocolate bars and 1000 marshmallows:
   a. How many S'mores can you make?

   ____

   ____

   ____

   ____

   b. What (if anything) will be left over, and how many of that item will there be?

   ____

   ____

   ____

   ____

Information

Chemists refer to the reactant which limits the amount of product that can be made from a given collection of original reagents as the **limiting reagent** or **limiting reactant**.

Critical Thinking Questions

3. Identify the limiting reagent for CTQ 2.

1 min

____

4. Based on the information given, which of the three ingredients (a marie biscuit, a chocolate bar or a marshmallow):

3 min

   a. weighs the most? ________________________
   b. weighs the least? ________________________
   c. Explain your reasoning.

   ____

   ____

5. If you have 10 kg of marie biscuits, 10 kg of chocolate bars and 10 kg of marshmallows:

3 min

   a. which item do you have the most of? ______________________
   b. which item do you have the least of? ______________________
   c. Explain your reasoning.

   ____

   ____

6. a. If you attempt to make S'mores from the material described in CTQ 5, what will be the limiting reagent?

1 min

____

b. How many gross of S'mores can you make? Use conversion factors.

3 min

____

____

____

c. How many gross of each of the two leftover items will you have? Use conversion factors.

3 min

____

____

____

2 min

d. How many kgs of each of the leftover items will you have? Use conversion factors.

____

____

____

2 min

e. How many kgs of S'mores will you have? Use conversion factors.

____

____

____

1½ min

7. Using B as the symbol for marie biscuits, Ch for chocolate bar, and M for marshmallow, write a "balanced chemical reaction" for the production of S'mores.

____

2 min

8. Using grammatically correct English sentences, explain why is it **not** correct to state that if we start with 10 kg each of B, Ch, and M, then we should end up 30 kg of S'mores.

____

____

____

4 min

9. Given the "balanced chemical reaction" for the production of S'mores from CTQ 7, calculate the mass of S'mores that can be made from 41.6 kg of chocolate bars, 14.2 kg of marie biscuits, and 5.82 kg of marshmallows.

____

____

____

____

____

____

____

____

Exercises

1. Given the balanced chemical reaction:

$$2\ NO_{(g)} + O_{2(g)} \rightarrow 2\ NO_{2(g)}$$

Calculate the mass of nitrogen dioxide that can be made from 30.0 grams of NO and 30.0 grams of O_2

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2. Zinc, Zn, and iodine, I_2, react to form zinc(II) iodide, ZnI_2. The reactants and the product are all solids at room temperature.

a) Write a balanced chemical reaction for this process.

____

b) Suppose that 50.0 g of zinc and 50.0 g of iodine are used to form zinc(II) iodide.

i. Assuming that the reaction goes to completion, which element will be totally consumed in the formation of the zinc(II) iodide?

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ii. What is the limiting reagent?

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iii. How many grams of zinc(II) iodide can be produced?

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iv. How many grams of the excess element remain unreacted? Very important question!!

3. Acetylene gas, HCCH, is commonly used in high temperature torches.
   a. Write a chemical equation for the reaction of acetylene with hydrogen gas (H_2) to form ethane (C_2H_6).
   b. How many grams of ethane can be produced from a mixture of 30.3 grams of HCCH and 4.14 grams of H_2?
4. Titanium (Ti) is a strong, lightweight metal that is used in the construction of rockets, jet engines, and bicycles. Ti can be prepared by reacting $TiCl_4$ with Mg metal at very high temperatures. The products are Ti*(s)* and $MgCl_2$.
   a. Provide a balanced chemical reaction for the reaction described above.
   b. How many grams of Ti metal can be produced from a reaction involving 3.54×10^4 g of Ti and 6.53×10^3 g of Mg?
5. The first step in the manufacturing process of phosphorous is the reaction below:

$$2\ Ca_3(PO_4)_2(s) + 6\ SiO_2(s) \rightarrow 6\ CaSiO_3(s) + P_4O_{10}(g)$$

   The MM of $Ca_3(PO_4)_2(s)$ is 310.2 g/mole and the MM of $SiO_2(s)$ is 60.1 g/mole. If 20.0 g of $Ca_3(PO_4)_2(s)$ and 20.0 g of $SiO_2(s)$ are reacted, how many grams of $P_4O_{10}(g)$ can be produced?

6. How many grams of N_2 (28.01 g/mole) can be obtained by reacting 24.5 g of NH_3 (17.03 u) with 30.8 g of O_2 (32.00 u)

$$4\ NH_3(g) + 3\ O_2(g) \rightarrow 2\ N_2(g) + 6\ H_2O\ (\ell)$$

ChemActivity 48, pp. 282-285

Redox Reactions

(Where have all the electrons gone?)

Model 1: The chemical reaction of $Zn_{(s)}$ and $Cu^{2+}_{(aq)}$

When a bar of zinc is placed in a 1.0 M copper(II) nitrate solution and left to stand for a while, solid copper is seen to deposit on the zinc bar, and some Zn^{2+} ions are found in solution. When equilibrium is reached in this system, essentially all of the copper ions have been precipitated out as solid copper (assuming that Cu^{2+} is the limiting reagent).

Reactions such as this involve an explicit transfer of electrons between chemical species and are known as **oxidation-reduction**, or **redox**, reactions.

$$Zn(s) + Cu^{2+}(aq) \leftrightarrow Zn^{2+}(aq) + Cu(s) \qquad ①$$

Critical Thinking Questions

1. Identify the reactant in equation ① that:
   a. Loses electrons

   ____

   b. Gains electrons

   ____

2. How many electrons are transferred when:
   a. one Zn atom reacts with one Cu^{2+} ion?

   ____

   b. one mole of Zn reacts with one mole of Cu^{2+}?

   ____

Model 2: Oxidation and Reduction

Oxidation-reduction reactions are sometimes divided into half-reactions to separate and clarify the electron transfer process. The species that loses electrons is said to be oxidised, and the species that gains electrons is said to be reduced. The oxidised species often referred to as the reducing agent. The substance that is reduced is referred to as the oxidising agent.

The half-reactions that describe the electron transfer process are:

$$Zn(s) \leftrightarrow Zn^{2+}(aq) + 2e^-$$

$$Cu^{2+}(aq) + 2e^- \leftrightarrow Cu(s)$$

3. Which species is oxidised in equation ①? Reduced?

____

4. Which species is the oxidising agent in equation ①? The reducing agent?

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5. How can the electron transfer process be stopped once the zinc has been placed into the Cu^{2+} solution?

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Model 3: Results of placing metal bars in a variety of solutions at 25˚C

Metal Bar	Ion Solution	Concentration of ions at equilibrium (M)	
Zn	Cu^{2+}	$[Cu^{2+}] \approx 0$	$[Zn^{2+}] \approx 1.0$
Zn	K^{+}	$[K^{+}] \approx 1.0$	$[Zn^{2+}] \approx 0$
Co	Ni^{2+}	$[Ni^{2+}] \approx 0.1$	$[Co^{2+}] \approx 0.9$
Co	Cu^{2+}	$[Cu^{2+}] \approx 0$	$[Co^{2+}] \approx 1.0$
Co	Cr^{3+}	$[Cr^{3+}] \approx 1.0$	$[Co^{2+}] \approx 0$

The results were obtained with metal bars large enough so that the limiting reagent in any redox reaction with the solution was the ion in solution.

Critical Thinking Questions

6. For each of the five experiments described in Model 3, write the balanced chemical equation (no "e^-" appears in the balanced chemical equation) for the redox reaction that ***could*** occur between the metal bar and the ion in solution. Note that the same number of electrons must be lost and gained in the transfer process. In each case indicate the oxidising agent and the reducing agent.

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Exercises

1. Identify the reducing agent and the oxidizing agent in each of the following reactions.

   a. $Br_2(aq) + Hg(s) \leftrightarrow 2\ Br^-(aq) + Hg^{2+}(aq)$

   b. $2\ Co^{3+}(aq) + 2\ Br^-(aq) \leftrightarrow Br_2(aq) + 2\ Co^{2+}(aq)$

   c. $Cl_2(aq) + 2\ Br^-(aq) \leftrightarrow 2\ Cl^-(aq) + Br_2(aq)$

d. $2\ H^{+}(aq) + Zn(s) \leftrightarrow H_2(aq) + Zn^{2+}(aq)$

e. $S_2O_8^{2-}(aq) + Zn(s) \leftrightarrow Zn^{2+}(aq) + 2\ SO_4^{2-}(aq)$

f. $Au^{3+}(aq) + Fe(s) \leftrightarrow Au(s) + Fe^{3+}(aq)$

2. Assume that all of the stoichiometric coefficients for the reactions in Ex. 1 represent molar quantities. How many electrons are transferred when each reaction takes place?

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Total: 36 mins

Rules for Balancing Half-reactions

(net ionic equations, acidic or basic solutions)

*Adapted from Haverford College, Chemistry 100, POGIL exercise on Oxidation Numbers and Balancing Half Reactions, 2013

Model 1: Balancing a half-reaction in acidic medium

Illustrated for reduction of sodium dichromate ($Na_2Cr_2O_7$) to chromium(III) ions in acidic solution. All ions may be safely assumed to be in acidic aqueous solution unless otherwise stated.

Start by writing unbalanced equation from known info.	$Na_2Cr_2O_7 \rightarrow Cr^{3+}$
Assume that soluble ionic species will dissolve, and **remove** spectator ions (in example: Na^+ is spectator ion)	$2Na^+ + Cr_2O_7^{2-} \rightarrow Cr^{3+}$ $Cr_2O_7^{2-} \rightarrow Cr^{3+}$
Assign oxidation numbers to element that is oxidized or **reduced** (in this case)	+6 +3
Balance elements except H and O	$Cr_2O_7^{2-} \rightarrow 2Cr^{3+}$
Balance the O by adding H_2O to the side that has too few O.	$Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 7H_2O$
Balance the H by adding H^+ to the side that has too few H.	$Cr_2O_7^{2-} + 14H^+ \rightarrow 2Cr^{3+} + 7H_2O$
Balance the charge of the half-reaction by adding electrons to the side that needs them. The charge on the left-hand side of the arrow must be equal to the charge on the right-hand side.	$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$ $+6 \rightarrow +6$

Exercises

1. Write balanced half-reactions as net ionic equations for each of these processes in acidic medium, and identify whether oxidation or reduction takes place.
   a. H_2SO_3 (sulfurous acid) to HSO_4^- (hydrogen sulfate)

3 mins

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   b. MnO_4^- to Mn^{2+}

3 mins

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   c. Oxalic acid ($H_2C_2O_4$) to carbon dioxide

3 mins

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   d. O_2 to water

3 mins

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Model 2: Balancing a half-reaction in basic medium

Complete balancing the half-reaction in acidic medium	$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$
Add OH^- to both sides of the half-reaction, the number of OH^- added should equal the number of H^+.	$Cr_2O_7^{2-} + 14H^+ + \mathbf{14OH^-} + 6e^- \rightarrow 2Cr^{3+} + 7H_2O + \mathbf{14OH^-}$
Make water where you have both OH^- and H^+ on the same side of the reaction	$Cr_2O_7^{2-} + \mathbf{14H_2O} + 6e^- \rightarrow 2Cr^{3+} + 7H_2O + 14OH^-$
Cancel out water molecules that appear on both sides of the half reaction	$Cr_2O_7^{2-} + 7H_2O + 6e^- \rightarrow 2Cr^{3+} + 14OH^-$

Exercises

2. Write balanced half-reactions as net ionic equations for each of these processes in basic medium, and identify whether oxidation or reduction takes place.
   e. Iron metal to solid ferric oxide (iron(III)oxide)

4 mins

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   f. Sodium sulfite to sodium sulfate

4 mins

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   g. Sodium chromate (Na_2CrO_4) to chromium(III) oxide ($Cr_2 O_3$)

4 mins

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Model 3: Putting Half-reactions together for balanced Redox reactions

Balancing redox reactions is helped by thinking of a redox reaction as the sum of two "half-reactions". To obtain balance, the **reduction half-reaction** must produce the same number of electrons as are consumed in the **oxidation half-reaction**.

If the half-reactions don't have the same number of electrons, multiply the coefficients of one or both half-reactions by a small integer so that the number of electrons becomes the same.

Then add the half-reactions together, and cancel out the electrons. You may also be able to cancel out H_2O, H^+ or OH^- (none of these should appear on both sides of the equation).

Once you have added the half-reactions together, you will be left with the **net ionic equation**, phases **(solid, liquid and gas)** must be shown in the net ionic equation. If **spectator ions** were removed, the need to be re-introduced and a **total ionic equation** must be written.

Exercises

Note: Total ionic equations are required along with net ionic equations, IF spectator ions were present initially.

3. Pair up any two half-reactions in acidic solution (from page 1) to create a balanced REDOX net ionic equation.

4 mins

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4. Pair up two half reactions in basic solution (from page 2) to create a balanced REDOX net ionic equation.

4 mins

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Model 4: Common Oxidation Numbers

The following is a table of common oxidation numbers. (The zero oxidation number is found in all pure elements, and is omitted from the table). Similar tables may be found in most General Chemistry textbooks, although there is no consensus among chemists for which oxidation numbers are “common”.

H -1, +1																	He
Li +1	Be +2											B +3	C -4 to +4	N -3, +3, 5	O -2	F -1	Ne
Na +1	Mg +2											Al +3	Si +4	P -3, +3, 5	S -2, +4, 6	Cl -1, +1, 7	Ar
K +1	Ca +2	Sc +3	Ti +2, 4	V +2, 4, 5	Cr +2, 3, 6	Mn +2, 4, 7	Fe +2, 3	Co +2, 3	Ni +2	Cu +1, 2	Zn +2	Ga +3	Ge -4, +4	As -3, +3, 5	Se -2, +4, 6	Br -1, +1, 5	Kr
Rb +1	Sr +2	Y +3	Zr +4	Nb +4, 5	Mo +3, 4, 6	Tc +4, 7	Ru +2, 3, 4	Rh +1, 3	Pd +2	Ag +1	Cd +2	In +1, 3	Sn +2, 4	Sb +3, 5	Te -2, +4, 6	I -1, +1,5,7	Xe
Cs +1	Ba +2	La +3	Hf +4	Ta +5	W +4, 5, 6	Re +3,4,6,7	Os +4, 8	Ir +3, 4	Pt +2, 4	Au +1, 3	Hg +1, 2	Tl +1, 3	Pb +2, 4	Bi +3	Po	At	Rn
Fr +1	Ra +2	Ac +3	Rf	Db	Sg	Bh	Hs	Mt	Ds	Uuu	Uub		Uuq				
			Ce +3, 4	Pr +3	Nd +3	Pm +3	Sm +3	Eu +3	Gd +3	Tb +3	Dy +3	Ho +3	Er +3	Tm +3	Yb +3	Lu +3	
			Th +4	Pa	U +3, 4, 6	Np +3, 4, 5	Pu +3, 4, 6	Am +3, 4	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

Critical thinking Questions

1. Which ions in this table have only a single common oxidation number? How is this common oxidation number related to the group number?

2 mins

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2. Including the elements with multiple common oxidation numbers, what generalizations can you make about the oxidation numbers based on the position in the periodic table?

2 mins

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APPENDIX C

CHEMORGANISER RESOURCES

INTRODUCING THE MOLE

Problem

Find the **mass**, in grams, of **3 moles** of sodium carbonate?

Before you start

- The **formula** is a group of chemical symbols which represent a molecule in a kind of chemical shorthand. They tell you which elements have combined to form a compound and their quantities. For example, the formula for ammonia is NH_3. This formula is also one way of representing one molecule of ammonia and it shows that the molecule consists of 1 atom of nitrogen and 3 atoms of hydrogen.
- On the atomic mass scale, ^{12}C = 12u, a nitrogen atom has an average mass of 14.01 atomic mass units (u) and hydrogen has 1.01 u. Therefore, the mass of ammonia (NH_3) molecule is (1 x 14.01) + (3 x 1.01) = 17.04 u. This is known as the **formula mass (FM_R) or molecular mass (MM_R)** depending on whether the compound is ionic or molecular/covalent. **R** means **relative** to ^{12}C.
- The **molar mass (MM)** of a substance (element or compound) is often used in chemistry and it represents a large quantity of particles. **This quantity is called a mole.** We can say that 17.04 g of ammonia contains one mole of ammonia molecules (where the mole represents a very large number: **6.022 x 10^{23} items**).
- This can be applied widely: Chloroform has the formula $CHCl_3$. From the Periodic Table the average atomic mass of carbon is 12.01 u and of chlorine is 35.45 u. Therefore, the molecular mass of $CHCl_3$ will be MM_R = (1 x 12.01) + (1 x 1.01) + (3 x 35.45) = 119.37 u. The **molar mass (MM)** of chloroform is **119.37 g/mol** which means 1 mole of chloroform molecules has a mass equals to 119.39 g.
- **The molar mass (MM)** can be written as a conversion factor

$$\frac{1\ mol\ CHCl_3}{119.37\ g\ CHCl_3} \quad \text{or} \quad \frac{119.37\ g\ CHCl_3}{1\ mol\ CHCl_3}$$

Concepts

Formula mass (FM_R), molecular mass (MM_R), atomic mass unit (u), mole (mol), molar mass (MM).

Strategy

You are given the number of moles of sodium carbonate and asked to calculate the mass of the sample in grams.

1. Write the correct chemical formula for sodium carbonate
2. Calculate the formula/molecular mass of sodium carbonate based on the average atomic masses of the elements given on the Periodic Table.
3. Re-write the formula/molecular mass as the **molar mass**, identify the **conversion factor**.
4. Use the conversion factor method to find the mass (in grams) of 3 moles of sodium carbonate

Chemorganiser, G Sirhan and N Reid (2002)

Solution

1. The formula for sodium carbonate is **Na_2CO_3**
2. From the Periodic Table, the average atomic masses for Na = 22.99u, C = 12.01u, O = 16.00u, so the **formula mass** for
   FM_R (Na_2CO_3) = (2 x 22.99) + (1 x 12.01) +(3 x 16.00) = 105.99 u
3. Interpret the formula mass as molecular mass
   MM **(Na_2CO_3)** = 105.99 g/mol
   $$\frac{105.99\ g\ Na_2CO_3}{1\ mol\ Na_2CO_3} \quad \text{or} \quad \frac{1\ mol\ Na_2CO_3}{105.99\ g\ Na_2CO_3}$$
4. Use the conversion factor method to find **grams of Na_2CO_3**

   Asked? Given

   $$g\ Na_2CO_3? \quad \frac{3\ mol\ Na_2CO_3}{1} \times \frac{105.99\ g\ Na_2CO_3}{1\ mol\ Na_2CO_3}$$
   $$= 317.97\ g$$

Self assessment

How many moles are in the following:
(a) 11.7 μg of sodium chloride
(b) 27.0 g of water
(c) 1 x 10^5 g potassium sulfate

Summary

- The **formula** is a group of chemical symbols which represent a compound in a kind of chemical shorthand.
- The **molar mass** of a substance (element or compound) is often used in chemistry and represents a **mole** of particles of that substance.

Answers: (a) 2.00 x 10^{-7} mol (b) 1.50 mol (c) 570 mol

Chemorganiser, G Sirhan and N Reid (2002)

QUANTITIES THAT REACT TOGETHER

(Reaction Stoichiometry)

Problem

Magnesium and oxygen react together to form magnesium oxide. What **mass** of oxygen is needed to react completely with 12.0 g of magnesium?

Before you start

- A balanced chemical equation gives all the vital information about the ratio in which substances react to form products
- For example, look at: $2\ H_2 + O_2 \rightarrow 2\ H_2O$
  - This equation says that **2 molecules** of hydrogen react with **1 molecule** of oxygen to form **2 molecules** of water.
  - It equally says that 200 molecules of hydrogen react with 100 molecules of oxygen to form 200 molecules of water.
  - More usefully, it also says that **2 moles** of **hydrogen molecules** react with **1 mole** of **oxygen molecules** to form **2 moles** of **water molecules**.

Concepts

Balanced chemical equation, reactant, product, gram, mole, formula/molecular mass, stoichiometric factor

Strategy

You are given the mass of one of the reactants (magnesium) and asked to calculate the needed mass of the other one (oxygen) to react completely with the given amount of magnesium.

1. Write the balanced equation for the reaction (try include phases if you can)
2. Interpret the equation
3. Identify the ***stoichiometric factor*** (this will not influence the significant figures of your answer)
4. Use the conversion factor method to find **grams of O_2** needed

Chemorganiser, G Sirhan and N Reid (2002)

Solution

1. Write the balanced equation for the reaction

$$2\ Mg(s) + O_2(g) \rightarrow 2\ MgO(s)$$

2. Interpret the equation

   2 moles of Mg react with 1 mole of O_2 to give 2 moles of MgO

3. Identify the ***stoichiometric factor***

   *Remember that you seek to relate oxygen to magnesium

$$\frac{2\ mol\ Mg}{1\ mol\ O_2} \quad \text{or} \quad \frac{1\ mol\ O_2}{2\ mol\ Mg}$$

4. Use the conversion factor method to find **grams of O_2** needed

Asked? Given

$$g\ O_2\ ? \quad \frac{12.0 g\ Mg}{1} \times \frac{1\ mol\ Mg}{24.31 g\ Mg} \times \frac{1\ mol\ O_2}{2\ mol\ Mg} \times \frac{(2 \times 16.00) g\ O_2}{1\ mol\ O_2}$$

$$= 7.90 g\ O_2\ (3\ SF)$$

Therefore, the mass of oxygen needed to react completely with 12.0 g Magnesium is 7.90 g

Self assessment

Aluminium metal reacts with hydrochloric acid to form aluminium chloride and hydrogen gas. How many grams of aluminium needed to form 3.65 g of aluminium chloride?

Summary

- Always use properly balanced reactions
- Identify the correct ***stoichiometric factor***, there are always irrelevant stoichiometric factors
- Use the conversion factor method and make sure both your units and labels cancel

Answers: $2\ Al(s) + 6\ HCl(aq) \rightarrow 2\ AlCl_3(aq) + 3\ H_2(g)$

0.739g of Al are needed to react to produce 3.65g of $AlCl_3$ product

Chemorganiser, G Sirhan and N Reid (2002)

LIMITING REACTANTS

The limiting reactant (or reagent) can only be identified through calculations, unless otherwise stated. It is important to find the limiting reactant as this dictates how much product can be formed.

Problem

Consider the following reaction:
$4 NH_3 (g) + 5 O_2 (g) = 4 NO (g) + 6 H_2O (g)$
How many **grams** of NO will form if 1.50 g of NH_3 reacts with 1.85 g of O_2 ?

Before you start

- Any **chemical reaction** stops as soon as any **ONE** of the **reactants** is **totally used up.**
- The **reactant** that consumed completely in a reaction is called the **limiting reactant** or **limiting reagent** because it determines, or limits, the amount of product formed. The other **reactants** are sometimes called **excess reactants** or **excess reagents**.
- The quantities of products formed in a reaction are always determined by the quantity of the limiting reactant.

Concepts

Chemical reaction, reactant, product, limiting reactant, excess reactant, consumed.

Strategy

You are given a chemical reaction and the quantities of the reactants (NH_3 and O_2), and you are asked to calculate the number of grams of NO, a product, that forms.

1. Write the balanced equation for the reaction
2. Interpret the equation in terms of molar quantities and their relationships
3. Use the conversion factor method to find how many grams of product **could** be formed by each reactant, **if the other reactant was in excess:**
   a. Calculate the grams of NO formed from NH_3
   b. Calculate the grams of NO formed from O_2
4. Determine the limiting reactant (the reactant who give less grams of product NO),and the mass formed from the limiting reactant is the answer.

Chemorganiser, G Sirhan and N Reid (2002)

Solution

(a) Write the balanced equation for the reaction

$$4 NH_3(g) + 5 O_2(g) \rightarrow 4 NO(g) + 6 H_2O(g)$$

(b) Interpret the equation in terms of molar quantities

4 moles of NH_3 react with 5 moles of O_2 to give 4 moles of NO and 6 moles of water

(c) Use the conversion factor method to find how many grams of NO product **could** be formed

a. Assume O_2 is in excess, how many grams of NO could be formed from 1.50 g NH_3?

Asked? Given

$$g\,NO ? \quad \frac{1.50 g\,NH_3}{1} \times \frac{1\,mol\,NH_3}{(14.01 + 3 \times 1.01) g\,NH_3} \times \frac{\mathbf{4\,mol\,NO}}{\mathbf{4\,mol\,NH_3}} \times \frac{(14.01 + 16.00) g\,NO}{1\,mol\,NO}$$

$$= 2.64\,g\,NO\,(3\,SF)$$

b. Assume NH_3 is in excess, how many grams of NO could be formed from 1.85 g O_2?

Asked? Given

$$g\,NO ? \quad \frac{1.85 g\,O_2}{1} \times \frac{1\,mol\,O_2}{(2 \times 16.00) g\,O_2} \times \frac{\mathbf{4\,mol\,NO}}{\mathbf{5\,mol\,O_2}} \times \frac{(14.01 + 16.00) g\,NO}{1\,mol\,NO}$$

$$= 1.39\,g\,NO\,(3\,SF)$$

Self assessment

(a) 2.00 g of zinc metal is placed in an aqueous solution containing 2.50 g of silver nitrate, causing the following reaction to occur: $Zn(s) + 2AgNO_3(aq) \rightarrow 2Ag(s) + Zn(NO_3)_2(aq)$
How many grams of Ag will form?

(b) Consider the reaction: $2 Al(s) + 3 Cl_2(g) \rightarrow 2AlCl_3(s)$
A mixture of 40.50 g of Al and 3.0 moles of Cl_2 are allowed to react. Which is the limiting reactant? How many grams of $AlCl_3$ are formed?

Answers: (a) 1.59 g
(b) Al, 200.25 g

Chemorganiser, G Sirhan and N Reid (2002)

What if the question asks how much reactant will remain after the reaction?

(e) Steps (a) to (d) are still necessary to determine which reactant is in excess and which reactant is considered as limiting

O_2 is the limiting reagent

NH_3 is in excess, but it does not state **how much** NH_3 wass in excess

g NH_3 remaining/in excess = g NH_3 before rxn – g NH_3 reacted/used in rxn

= 1.50 g NH_3 – x g NH_3 reacted

(f) $NH_3(g) + 5\ O_2(g) \rightarrow 4\ NO(g) + 6\ H_2O(g)$

(g)

4 moles of NH_3 react with 5 moles of O_2 to give 4 moles of NO and 6 moles of water

(h) Use the conversion factor method to find how many grams of NO product **could** be formed

c. Assume O_2 is in excess, how many grams of NO could be formed from 1.50 g NH_3?

Asked? Given

$$\text{g NO ?}\quad \frac{1.50\text{g NH}_3}{1} \times \frac{1\text{ mol NH}_3}{(14.01 + 3 \times 1.01)\text{g NH}_3} \times \frac{\boldsymbol{4\ mol\ NO}}{\boldsymbol{4\ mol\ NH_3}} \times \frac{(14.01 + 16.00)\text{g NO}}{1\text{ mol NO}}$$

= 2.64 g NO (3 SF)

d. Assume NH_3 is in excess, how many grams of NO could be formed from 1.85 g O_2?

Asked? Given

$$\text{g NO ?}\quad \frac{1.85\text{g O}_2}{1} \times \frac{1\text{ mol O}_2}{(2 \times 16.00)\text{g O}_2} \times \frac{\boldsymbol{4\ mol\ NO}}{\boldsymbol{5\ mol\ O_2}} \times \frac{(14.01 + 16.00)\text{g NO}}{1\text{ mol NO}}$$

= 1.39 g NO (3 SF)

(i) Determine the limiting reactant (the reactant who give less grams of product NO), and the mass formed from the limiting reactant is the answer.

Because O_2 would yield less grams of product NO, it is the limiting reactant. The mass of NO formed

Chemorganiser, G Sirhan and N Reid (2002)

OXIDATION NUMBERS

It is often useful to follow chemical reactions by looking at changes in the oxidation numbers of the atoms in each compound during the reaction. Oxidation numbers also play an important role in the systematic nomenclature of the chemical compounds.

Problem

Determine the oxidation numbers of the underlined atoms in the following:

a) $\underline{S}_8$ b) $\underline{As}O_3^{3-}$ c) $K\underline{Mn}O_4$ d) $K_2\underline{Cr}_2O_7$

Before you start

- The oxidation number (also known as the oxidation state) of an atom is the charge that the atom would have had if the compound was composed of ions
- Valency is the oxidation number with no sign
- There are some guidelines in assigning oxidation states (numbers) to atoms in a compound or ionic species

GENERAL RULES

	Oxidation state	Examples	Exceptions
Group 1A (Li, Na, K...)	+1	LiCl, NaF	....
Group IIA (Be, Ca, Mg...)	+2	$BeCl_2$, $CaSO_4$	....
Group IIIA (Al, B, Ga...)	+3	$AlCl_3$, BF_3	....
Oxygen	-2	Na_2**O**, H_2**O**	Peroxides like H_2O_2
Hydrogen	+1	H_2S, HCl	Hydrides like NaH
All elements	Zero per atom	**Na** is zero	....
Mono-atomic ions	Charge on ion	Ca^{2+} is +2	....

- The sum of the oxidation numbers in a neutral compound is zero
  e.g. in H_2O $2(+1) + (-2) = 0$
- The sum of the oxidation numbers in a polyatomic ion is equal to its charge
  e.g. in SO_4^{2-} $(+6) + 4(-2) = -2$

Concepts

Oxidation state, main group in the periodic table, mono-atomic ion, polyatomic ion, charge

Strategy

1) Identify the "**GENERAL RULE**" for each atom in the molecule or ion
2) Let x = the oxidation state of the unknown atom
3) For a neutral compound the sum of the oxidation states is equal to zero
4) For a polyatomic ion the sum of the oxidation states is equal to the charge on the ion

Chemorganiser, G Sirhan and N Reid (2002)

Solution

a) For S in S_8 the answer is 0

b) For As in $(As\ O_3)^{3-}$

$x + 3(-2) = -3$

$x + -6 = -3$

$x = +3$ (the oxidation state of the Arsenic atom in the ion)

c) For Mn in K Mn O_4

$1(+1) + 1(x) + 4(-2) = 0$

$1 + x + -8 = 0$

$x = +7$ (the oxidation state of Manganese atom in the ion)

d) For Cr in K_2 Cr_2 O_7

$2(+1) + 2(x) + 7(-2) = 0$

$2 + 2x + -14 = 0$

$x = +6$ (the oxidation state of Chromium atom in the ion)

Self assessment

Determine the oxidation state of the underlined atoms in the following:

a) $H_2\underline{S}O_4$ b) $K_2\underline{Mn}O_4$ c) $K\underline{Cl}O_3$
d) $\underline{S}O_2$ e) $Mg_3\underline{N}_2$ f) $Ca_3(\underline{P}O_4)_2$
g) $Ba\underline{Cr}O_4$ h) $\underline{I}O_4^-$ i) $\underline{V}O^{+2}$

Summary

- All Group I elements are +1
- All Group II elements are +2
- All Group VII elements are -1 when ionic
- All compounds have a sum oxidation state of zero
- All elemental substances are zero

Answers: +6, +6, +5, +4, -3, +5, +6, +7, +4

Chemorganiser, G Sirhan and N Reid (2002)

REDOX REACTIONS

Chemical equations do not come already balanced. This must be done before the equation can be used in a chemically meaningful way

Problem

Balance the redox equation for the reaction between copper metal and nitric acid, HNO_3, to give Cu^{2+} and NO.

Before you start

- A balanced equation has equal numbers of each type of atom on each side of the equation.
- Oxidation- reduction reactions involved the transfer of electrons from one atom to another. (You can't have one without the other)
- Oxidation is electron loss (oxidation number of an atom becomes larger/more positive)
  Reduction is electron gain (oxidation number of an atom becomes smaller/less positive)
- If there is a neutral compound which is soluble in aqueous medium, break the compound down in to ions before proceeding. One of the ions will be involved in the reaction, the other is a spectator ion
- The aqueous medium used is either acidic or basic

Concepts

Balanced equation, oxidation number, reduction, oxidation, redox, electron, loss or gain electrons, spectator ions and half-reaction.

Strategy

1. Write the half equations:
   - For the oxidation, electron loss (oxidation state of an atom becomes larger/more positive)
     $Cu \rightarrow Cu^{2+}$ oxidation state of Cu atom increased from 0 to 2+
   - For the reduction, electron gain (oxidation state of an atom becomes smaller/less positive)
     $NO_3^- \rightarrow NO$ oxidation state of N atom decreased from 5+ to 2+
2. Balance by inspection all elements (except O and H)
3. Balance the oxygens by adding H_2O to the opposite side of the half-reaction.
4. Balance the hydrogens by adding H^+ to the opposite side of the half-reaction.
5. Balance the charges by adding electrons, e^-, to the more positive side of the half reaction.
6. Multiply each half-reaction by a factor, so that the number of electrons transferred is equal
7. Add both half reactions together. You can "cancel" species which appear on both sides.
8. If the reaction is in basic medium, neutralise any H^+ ions by adding the same amount to OH^- to both sides of the reaction. Remember that $H^+ + OH^- \rightarrow H_2O$
9. Cancel excess water molecules

Solution

1. Write the half equations based on the change in oxidation numbers

   Oxidation: $\overset{0}{Cu} \rightarrow \overset{+2}{Cu^{2+}}$

   Reduction: $\overset{+5\ -2}{NO_3^-} \rightarrow \overset{+2\ -2}{NO}$

2. Balance by inspection all elements (except O and H)

   Oxidation: $Cu \rightarrow Cu^{2+}$
   Reduction: $NO_3^- \rightarrow NO$

3. Balance the oxygens by adding H_2O to the opposite side of the half-reaction.

   Oxidation: $Cu \rightarrow Cu^{2+}$
   Reduction: $NO_3^- \rightarrow NO + 2\,H_2O$

4. Balance the hydrogens by adding H^+ to the opposite side of the half-reaction.

   Oxidation: $Cu \rightarrow Cu^{2+}$
   Reduction: $NO_3^- + 4\,H^+ \rightarrow NO + 2\,H_2O$

5. Balance the charges by adding electrons, e^-, to the more positive side of the half reaction.

   Oxidation: $Cu \rightarrow Cu^{2+} + 2e^-$
   Reduction: $NO_3^- + 4H^+ + 3\,e^- \rightarrow NO + 2\,H_2O$

6. Multiply each half-reaction by a factor, so that the number of electrons transferred is equal

   Oxidation: **3** $(Cu \rightarrow Cu^{2+} + 2e^-)$
   Reduction: **2** $(NO_3^- + 3\,e^- + 4H^+ \rightarrow NO + 2\,H_2O)$

7. Add both half reactions together. Remember to add phases

   Oxidation: $3\,Cu \rightarrow 3\,Cu^{2+} + 6e^-$
   Reduction: $2\,NO_3^- + 6\,e^- + 8H^+ \rightarrow 2\,NO + 2\,H_2O$

   $3\,Cu(s) + 2\,NO_3^-(aq) + 8H^+(aq) \rightarrow 3\,Cu^{2+}(aq) + 2\,NO(g) + 2\,H_2O\,(l)$

8. Neutralise H^+ ions by adding the same amount to OH^- to **both** sides of the reaction

   $3\,Cu(s) + 2\,NO_3^-(aq) + 8H^+(aq) + \mathbf{8OH^-(aq)} \rightarrow 3\,Cu^{2+}(aq) + 2\,NO(g) + 2\,H_2O\,(l) + \mathbf{8OH^-(aq)}$

   Water is formed:

   $3\,Cu(s) + 2\,NO_3^-(aq) + 8\,H_2O(\,l\,) \rightarrow 3\,Cu^{2+}(aq) + 2\,NO(g) + 2\,H_2O\,(l) + 8OH^-(aq)$

9. Cancel excess water molecules

   $3\,Cu(s) + 2\,NO_3^-(aq) + 6\,H_2O(\,l\,) \rightarrow 3\,Cu^{2+}(aq) + 2\,NO(g) + 8OH^-(aq)$

Self assessment

Write balanced equations for the following redox reactions:

(a) The reaction of permanganate ion (MnO_4^-) with bromide ion (Br^-) in acidic solution to form Mn^{2+} ion and bromine gas (Br_2).

(b) The oxidation of Cr^{3+} ions by hydrogen peroxide (H_2O_2) in basic solution to give chromate ions (CrO_4^{2-}). In this reaction the hydrogen peroxide is converted to water.

Answers:
(a) $2\,MnO_4^-(aq) + 10\,Br^-(aq) + 16\,H^+(aq) \rightarrow 2Mn^{2+}(aq) + 8\,H_2O\,(l) + 5\,Br_2(g)$
(b) $2\,Cr^{3+}(aq) + 3H_2O_2(aq) + 10\,OH^-(aq) \rightarrow 2\,CrO_4^{2-}(aq) + 8\,H_2O\,(l)$

Chemorganiser, G Sirhan and N Reid (2002)

APPENDIX D

Oxidation Numbers Chemorganiser Pilot Questionnaire

1. Describe using the Chemorganiser with reference to studying oxidation numbers
   - ☐ Used, essential to understand the topic
   - ☐ Used, helpful to understand the topic
   - ☐ Used, not very helpful to understand the topic
   - ☐ Did not use

2. Did you find using the Chemorganiser
   - ☐ Easy
   - ☐ Moderate
   - ☐ Difficult

APPENDIX E

POGIL STUDENT QUESTIONNAIRE

Thank you for participating in this questionnaire. Your responses will be treated as confidential and you will remain anonymous. Please answer as honestly as possible.

Use side 1

---

1. How did you experience the **pace** of the POGIL tutorials (i.e. how much was covered per session)?
   A. Fast, a lot of work was covered
   B. Normal, an average amount of work was covered
   C. Slow, we didn't get a lot done

2. How did you feel about **working in a group** in an **on-going** basis?
   A. Happy/Comfortable
   B. Neutral
   C. Unhappy/Uncomfortable

3. How **involved** were other group members during the POGIL tutorial sessions?
   A. Everyone participated fully
   B. One person did all the work
   C. Group participation varied from day to day

4. Would you have preferred random group member allocations by the instructor instead of choosing your own group?
   A. Yes
   B. No

5. How much **time** was used **productively** during a POGIL tutorial?
   A. 0 -25% productive (very low productivity)
   B. 26-50% productive (low productivity)
   C. 51-75% productive (fair productivity)
   D. 76-100% productive (high productivity)

6. Do you feel that POGIL has adequately **prepared** you for tests and exams?
   A. Yes, I feel well prepared
   B. Partially, I will have to do a fair amount to preparation on my own
   C. No, not at all

7. Give your response to this statement:
   *"I would **recommend** that POGIL is used next year **instead** of the original way in which our tutorials were structured."*
   A. Strongly agree
   B. Agree
   C. Neutral
   D. Disagree
   E. Strongly Disagree

CHEMORGANISER STUDENT QUESTIONNAIRE

Thank you for participating in this questionnaire. Your responses will be treated as confidential and you will remain anonymous. Please answer as honestly as possible.

Use side 1

---

8. How did you experience the **pace** of the CHEMORGANISER tutorials (i.e. how much was covered per session)?
   D. Fast, a lot of work was covered
   E. Normal, an average amount of work was covered
   F. Slow, we didn't get a lot done

9. How did you feel about **using** the CHEMORGANISER **individually** as a tool inside **and** outside of class?
   D. Happy/Comfortable
   E. Neutral
   F. Unhappy/Uncomfortable

10. How **involved** were you in the CHEMORGANISER tutorial sessions?
    A. I was highly involved, I used it to do self-assessment questions and prescribed examples
    B. I felt lost, I battled to use the CHEMORGANISER
    C. I did not feel that the CHEMORGANISERS were necessary to complete the tasks.

11. How much **time** was used **productively** during a CHEMORGANISER tutorial?
    E. 0 -25% productive (very low productivity)
    F. 26-50% productive (low productivity)
    G. 51-75% productive (fair productivity)
    H. 76-100% productive (high productivity)

12. Do you feel that CHEMORGANISERS have adequately **prepared** you for tests and exams?
    D. Yes, I feel well prepared
    E. Partially, I will have to do a fair amount to preparation on my own
    F. No, not at all

13. Give your response to this statement:
    *"I would **recommend** that CHEMORGANISERS are used next year **instead** of the original way in which our tutorials were structured."*
    F. Strongly agree
    G. Agree
    H. Neutral
    I. Disagree
    J. Strongly Disagree

APPENDIX F

TEST INSTRUMENT – YEAR 1 REDOX REACTIONS

Part B

Balanced the reaction between the potassium permanganate and hydrogen peroxide in acidic solution to form the manganese (II) ion and oxygen: $MnO_4^- + H_2O_2 \rightarrow Mn^{2+} + O_2$

Include in the answer:

- The oxidation number of each element
- The oxidising and reducing agent.
- Indicate the oxidation and reduction half-reactions.

10 marks

20 min

TEST INSTRUMENT – YEAR 2 MOLE CONCEPT AND STOICHIOMETRY

1. Balance the following chemical reaction

2 marks

$$Ca(OH)_2 + \quad NH_4Cl \rightarrow \quad CaCl_2 + \quad NH_3 + \quad H_2O$$

2. You have 5.00 g of each reactant; use the balanced equation to answer the questions that follow. Answers must have the correct number of significant figures:

5 marks

   a. How many grams of ammonia could be formed?

   b. Which compound is the limiting reagent? Give the formula.

1 mark

   c. State which compound is in excess and calculate how much of this reactant will remain after the reaction is complete.

4 marks

d. If you conducted this experiment in a laboratory and achieved a 65.00% yield, how many grams of ammonia did you actually produce? Give your answer with two decimal places.

3 marks

Total 15 marks

30 mins

APPENDIX G

FOCUS GROUP INTERVIEW – Year 1 POGIL

Me: I'd like to start off with a question: Did you guys understand what was expected of you in the POGIL tutorials i.e. the work that you had accomplished and the roles that you were put into?

S: Okay I did understand the roles, some of the roles were a bit funny though; not extremely useful – the technician, ja, um, some of them didn't involve the calculator work like in those positions the technicians would relax and not do much. Um, but the exercises and whatever were set out in a way that was quite understandable and balanced

A: Ja, I did understand what was expected of me. To be honest I feel like, um, it wasn't helping us in a way. WE were doing it in a group, sometimes we didn't understand what was happening: like we were not taught before – that was the problem.

K: Ja, well, I also did understand but then the problem is that most of the work was getting done in groups, so like myself, when I get confused I lose concentration. I don't do work anymore, I let it go. Ja, that's the problem.

Me: Now, I want to ask you about the pace of the tutorials. Do you think the amount of work prescribed for you in those tutorials was realistic?

S: I think it as realistic perhaps on a more individual basis because the group work, if it was working properly (some days it would work properly, some days it wouldn't) we'd first discuss it and in that sense the time it was a bit short to finish the questions. But if it was individual it was realistic but for group work I think it was a bit much

K: Okay, I think it was realistic and even though we were not able to cover a lot of work, I think we were able to cover the most important stuff and then after that you can also go home and find out for ourselves[26]. So it was realistic.

A: Okay, ja, ja it was realistic because we learnt a lot. It helped us in a way to work independently, that we shouldn't depend on you all the time.

Me: Okay you mean "independently" not in the tutorials? In your own time?

A: Yes, Yes…

Me: Okay, now I want to talk about the actual POGIL worksheets themselves, do you remember what they looked like? I want you to just comment on the design of the sheet. Were you happy with the design? The organisation? The amount of text versus the amount of problems, things like that... the actual hard copy "things", what did you feel about it?

A: It was organised because in most cases we started with the Critical Thinking questions, in that way the harder questions so we could understand that we could do it

K: Well, I'm happy with the layout but I did think that we did start with the most easiest questions so that we can get started and then after that we got to the more difficult questions (laughs)

S: I liked, like in the last one, we had the info, like the steps in the beginning. Ja, that was, that was very helpful: in the questions after that you followed the steps and got to learn the steps. Um, sometimes I was a bit unsure about sections that we do then and sections that we don't do: those we can do later ourselves. We didn't always get to the end of the questions[28]. Um, but, overall the questions were very relevant and if it explains how to do it in the beginning, giving you all relevant info then followed the questions

Me: Based on what Shaun said, were you two ladies present for the last POGIL with the redox reactions? Were you there or not?

A & K: Yes, Ja, we were there

Me: Did you find a difference between that POGIL worksheet and the other ones like Shaun did? Did you prefer that one?

K: Yes I did, because like, eh, we usually have chemistry tutorials on Monday before the lectures so we don't know what is happening in that theme so that problem worksheet was more helpful than the others, the previous ones.

Me: Okay, it was actually from a different source, that POGIL worksheet. You agree with her? (A nods) Okay, now I want to ask you, do you think that POGIL prepared you for the assessments like the common test or were there too many things left out? What was your feeling: did you have to do a lot of self-study? Did you have to do a little bit of self-study?

K: Um, I don't think it helped me a lot because, like I said, when I get stuck I just lose concentration and I don't do work anymore. That kinda made me fall behind. So when it came to tests and stuff, I had to start from the beginning and do self-study[16] so ja, it didn't really help

S: The common test, the last question was very relevant to the latest POGIL session, um, the method of doing that last question wasn't really discussed properly in the tutorial guide, um and, it didn't go so well for me the last question but if I hadn't done the tutorial, I don't think I would have got any marks[17] for that section because it's not discussed properly in the tutorial guide as it was in the POGIL. But I didn't really study that section afterwards; I focused more on the beginning sections, so that question didn't go as well for me as it should have.

Me: And in general, for the other POGIL sessions, the mole concept and stoichiometry, do you think that it helped?

S: Ja, I believe it helped because, ja, I think my marks have increased a bit, but it could be the different semesters, but overall I think it has helped a bit. Um, I didn't study that much, which probably would have helped me, but, ja, I think that overall it helped and was very relevant to the common test

K: POGIL worked in mole concept, it improved my marks, they were very good. But overall I felt like my marks dropped. I don't know whether it was the group thing or I don't know what was the problem.

Me: Now, I just want to talk about the amount of effort it took you to participate in the groups. Was it difficult for you? Did you find it easy to participate in a group? In the questionnaire I gave you: "how involved were you?" and what sort of effort did that require from you to be involved in them?

S: Well the days were different for me; like some days you're a bit tired or had a bad weekend or whatnot. Those days I would not concentrate as much or be as involved in the group. Then some days you would have a good day and get involved. Also your roles – recorder was where I was most involved in the group as well as the manager. So when I was the presenter I would relax and sometimes the technician wouldn't have to calculate. So on those days you would just sit back, so it depends on your role and whatnot.

K: Also for me, I think it also depended on the role that I was given so um, like, if I was given, um a role for presenting I would be scared like the whole session that I have to speak in public and stuff. I couldn't really concentrate[7]. I'd just sit back and get the answers so that I could present it. I really don't like presenting so I think that it depends on the roles you're given, Ja. But other roles I was cool with them.

Me: Just to interject, did you guys stick to your roles in your group or were the roles flexible?

K: I tried to stick to the roles that I was given in a particular session

Me: And the rest of your group?

K: Yes (embarrassed laugh) but when you are given a role like the technician, or if the recorder sees that you are slacking she just takes the calculator and does the calculation herself.

A: Ja, um, I think that the recorder was the one that was benefitting most, because that person was writing everything that you were saying. Sometimes, you like, you were not concentrating and you didn't know what was happening, or maybe you were calculating something, you were busy. The recorder benefiting most, and sometimes we had group members who were late so we had more work to do and be a recorder at the same time

Me: Just to take you back, how involved do you think you were in (a percentage or even as an idea)? Was it taxing for you in groups? Would you prefer individual or not?

K: I did not enjoy the group work. I would prefer to work individually because in that way I think I would have benefitted. I would have known what is the problem. I think it is best to do it individually so that you know when you are wrong, because in a group you are not sure whether you know something or not.

A: I also like doing my work individually but after that to check my answers I would like to discuss it with my group[40]. So I think that maybe we should have done the questions individually and after that we can discuss, ja.

S: I also agree with that, um, also what was I going to say? (all laugh) Oh my word, okay, okay, the involvement was also depending on the group like halfway through you did change the groups. In the first group I did very well with, um that I was always quite involved, the people in the group were also committed to it but in the second group I was in, the other people weren't very committed as a result, I also wasn't very committed. So it depends on the group. Also sometimes, sometimes it was like I needed the group to be smaller because there were too many people doing the same or different things and discussing things at the same time. Whereas, sometimes it was just two of us, it was very helpful because we go to like bounce things off each other and discuss different ideas, but when there is a group it was very difficult to discuss different ideas.

Me: Now, I want to ask you the question, in general, across the POGIL sessions, how much time do you think was used productively and how much time do you think was wasted (not used optimally)? And you can also compare that to our original way of doing tutorials: how much time do you think you worked in the POGIL tutorials versus working productively in the original tutorials

K: In the beginning of POGIL, like we were closing relevant work every time. We used the time very productively but then as time went on, I think we got bored and we were not productive. Like in original tutorials, you were in front.

S: Okay, I found the POGIL more useful because in the tutorials we do a section, you give us questions to do, then we have time for those questions. Now, I'd sometimes do them very quickly because they weren't extremely like difficult and the whole class has to catch up. So in that sense I think we did more work, more useful work. In a group there are just four of us that need to catch up to each other and then move on. Ja so, if it's the whole class, you have to wait for the whole class to answer the question before you move on when with this one, it was just us: we got to move at a faster pace or a slower pace depending on what was needed[27].

Me: Now I'd like to ask you about the influence of POGIL on your study time? Did it increase your study time, decrease your study time? Did it make your study time experience more positive? A more negative experience?

K: Well, I think it increased my study time more because I was not really participating well in the POGIL sessions. So when I got home I had to study really hard from the beginning, so I think it did increase my study time.

S: Um, my study time I don't think was affected that much: I was doing the same before and after. But I thought POGIL notes were a bit more useful than the tutorial guides notes. The POGIL notes did not have references to the textbook so the tutorial guide was still useful in that sense. But overall, the POGIL notes, the exercises that we did in class, those were more useful to study from than the tutorial notes or textbook. Although, it didn't have references to the textbook, which I didn't like.

K: I think it depended on the sections, like the last section that we did now, it did increase my study time, but mole concept it didn't at all: I learnt mostly in class

Me: From those different roles, did you take/gain anything professionally? (K) the fact that you were forced to present help you or hinder you? Did you learn anything, did you gain anything from those roles?

K: I think it did because it prepared us for the future because when we are in a working environment there will be different roles which we will have to respect like in that way it helped me a lot

A: I also think it helped, because, um, when you know that you have a problem, like I'm a student, so I have to be able to deal with those problems; it will help me to prepare for the different roles I will have in the future.

S: I agree with that, also, group work in total, I wasn't very good at, but now we do it every week it became easier and easier as we went along. I learnt how to work in a group better. I do realise that you need to be comfortable in a group, when we changed it was ugh…

Me: How long would you have liked to have kept your original group?

S: Till the end. I enjoyed my original group, ja. My second group I didn't enjoy so much also, it's difficult to swop to a new group

Me: Finally, I want you to comment on this statement, so tell me whether you agree or disagree, strongly agree or strongly disagree, or if you don't care. The statement is: "I would recommend that POGIL is used next year instead of the original tutorials". Would you agree with using POGIL next year and how do you feel about it?

K: I wouldn't agree (laughs)

Me: Why?

K: Because like, I hate teamwork and I don't think sometimes it's productive. So I wouldn't recommend POGIL[38]

S: I don't agree with you: to an extent I did enjoy it. It helped me in some senses. I would agree with using POGIL again[39]

A: I think once a week would do, not every day, ja, once a week. Then you can see how they perform between POGIL and normal tutorials.

Me: To end with, do you have any comments you'd like to voice on POGIL?

Others: (laugh)

Me: Anything?

A: Ma'am, to be honest, I didn't like POGIL, it helped but…

Me: Do you think it was just the group work or was there anything else that made you uncomfortable?

A: I think it was the group work

K: Ya, because the worksheets were fine

A: Yeah that was ok, that's why I say, just the group work once a week would be better; not every day.

FOCUS GROUP INTERVIEW – Year 1 Chemorganiser

Me: Did you understand what was expected of you in the tutorials? I.e. how to use the Chemorganiser to do the work?

A: Um ja, I did. It was very simple to understand, it was very interactive and um I found the way it was laid out, it gave an overview of how to approach other problems as well

B: It also stated the outcomes of the sections, so I basically followed that and it prepared me better for the section as a whole.

Me: I want you to comment on how you experienced the tutorials. What I mean by that is, did you feel that the amount of work that I required you to do in those tutorials was realistic? The pace at which the work went?

B: Um, Yea, I did find it quite realistic. Um, you gave us enough problems to do in our allocated time. As well as, um, going through examples with us. So yea, I did find it realistic

A: Well, ah, most of the students in our group are quite lazy so the homework was appropriate. There was enough homework to do. And I think that the questions that you gave us in the class were very similar to those we experience in the test[18]. So that was, that was good.

Me: Alright, now I want to talk about the Chemorganisers themselves (those pages). Firstly, the layout and organization of the Chemorganiser - how did you experience that? Was it easy to use? Did you battle at certain places? Was there too much content? Was there too little content?

B: Um, I found them quite easy to use, the layout was very user-friendly. Um, especially the steps that you take to solve problems as well as examples

A: Well, at first I was confused about the structure, with the problems, and then you basically spoke about the outcomes of the section and then afterwards you continued with the example. There were certain things that I was confused about, until you explained it properly.

Me: Do you think that it is a tool that needs explanation or could you have done it individually? I am just curious.

B: Well, it could be done individually I think, but it is more beneficial when explained of course. At first you don't understand it, but then you grasp it. I think we were just new to the whole process

Me: Also, I had the comment that a lot of people could use the Chemorganiser when doing the work but some got left behind when I actually explained that chunk of theory or outcomes. Did you guys experience that and do you have any insights as to why that would have happened?

B: Um, well, at first it was a bit confusing like we could go through it and whatever but I did find that the outcomes had to be explained.

A: Well I agree with her. Basically if you went through your section notes and stuff, then you would understand the outcomes.

Me: So you agree that Chemorganiser must be used in conjunction with slides and large group lectures?

A: Yes, yes, it needs to be used with the tutorial teaching as well.

Me: Alright, so neither of you used it as a resource on its own?

A: No

B: No

Me: And in studying you used the slides and the Chemorganiser?

A: We used the slides for the theory part of it (laughs) and we used the Chemorganiser in our problems

Me: Do you think the Chemorganisers prepared you for the assessments like the common test you just wrote?

A: Well it definitely did. I mean, um uh, last semester I kinda was behind in the sections, the parts that were hard to understand but the Chemorganiser, if I get stuck on a particular question, then I know I can refer back to it.

B: Um, ok, ah, I had to look at it. I found the Chemorganisers very helpful, ah because, for example, for the acid and base, at first I didn't grasp that, then I went back to the Chemorganisers and then I used that to solve the problems when I was studying. It was very easy to grasp the content.

Me: Just to interject quickly, some people said that they found the Chemorganisers too easy and they didn't have a challenge/weren't stimulating. Do you have a comment on that?

B: The Chemorganiser was basically an outline of how to solve a problem. I found that there were challenging questions that we have in our tutorial guides, which you needed to grasp the Chemorganiser in order to do. I do find that there were challenging questions that I don't think the Chemorganiser made easier. It just gave you the basic idea of it.

A: Like a foundation

B: yes, basically just a foundation to start off your more difficult questions

Me: With the use of the Chemorganisers did you actually feel involved in the sessions? Or how did you feel during those sessions? Did you participate etc.? You don't only have to say positives…

A: Well, normally when I tackle the questions, if I get stuck on the questions, then I lose interest and I don't want to participate (move on further) but the Chemorganiser, if I'm stuck, then I know I've got a guide to help me through it. So like recently, I've been tackling all the problems easier[8].

B: Um, I agree with her, um, like before with the problems, we didn't really have a guideline to work through so we use to take much more longer. Now I find that when you give us exercises to do in class we can get through them and even start with the homework questions cause the Chemorganiser helps us understand the problem as well as shows us how to approach it.

Me: That brings me directly to my next question: when you look at your tutorials, how much time do you think you used productively, within the tutorials and compared to tutorials where the Chemorganisers weren't implemented? Evan a percentage or a general feeling: how much time did you think was productive and how much do you think was wasted on admin or when you don't know the concept.

B: OK, I find my tutorials quite productive, um, they have been improved with the Chemorganisers as well because in our tutorials we gain more than we do in the lectures and I find that we learn more when we are in the tutorials than outside. And with the Chemorganisers I find that we actually progress even more

A: Whereas, previously we tackled half the questions that you're giving us during the tutorial, now with the Chemorganiser we tackle most of the questions[29].

Me: Did you use the Chemorganiser when you were studying? Did it cut down on study time? Did it increase it? Because I mean, understanding the Chemorganiser also takes time. So from your perspective, how did it influence your studies?

B: I found that using the Chemorganiser has reduced the amount of study time I have to use because I, um, now grasp the work even more. So I just need to get the theory part and then the Chemorganisers help me with the problems and all of that.

A: I agree (laughs)

Me: Now, I just want you to comment on this statement. It was: "Would you recommend that Chemorganisers are used next year compared to the original way that I conducted the tutorials." To what degree do you agree/disagree?

B: Okay, I strongly agree that it should be used[41], ah, because I didn't only use my Chemorganisers for studying like for the tests and whatever. I also found they were useful in the practicals, when we had to do I understand our practicals, especially the precipitate stuff. So I used my Chemorganiser in conjunction with my practicals. So I do feel that they should be used next year

A: It should be used from first semester I think[42], ah, we started off a bit late… I was doing very badly the previous semester and with the Chemorganiser I felt the common test was easier for me because it highlighted the main concepts of each section.

Me: Just to round off, do you have any comments, positive or negative, that you would like to highlight so things can be changed next year

A: Maybe it should include a few more examples, I think. Maybe an easier one and a more difficult question so we can look at the differences that you have

B: Okay, I think that, um, maybe when it comes to the first part of it, that part should come a bit later, because um, when we get to the problem, we forget what was asked, so um ja, we get caught up with all the other stuff.

APPENDIX H

EXTERNAL OBERSERVARTION IN THE EARLY STAGES OF INTERVENTIONS – YEAR 1

The POGIL

The groups do seem to interact with their members well. The idea of getting them to interact, I think is a good one and you are the guide, rather than the instructor. If they can put heads together and the sum of their intelligence is greater than the number in the group. I think this system is sort of what we are looking for in tutorials, after all, if the group can throw ideas around. Plus, the old adage, if you, as students, can teach each other the topic, you learn yourself.

Rotating the manager, recorder etc., means ideally there are no free riders. There were perhaps 2 students in the whole class who seemed a little dubious of the whole idea.

The Chemorganiser

Talking to a couple of students, they thought the Chemorganiser polished up bits that they'd learnt in the large lectures. It is a smart recipe, but have they not already been given the recipe/ concept in the large group lectures?

Personally I prefer the POGIL method. Letting students interact and the group's output should be greater than their collective heads put together. It must be organised well and use the existing tutorial problems as well as extra POGIL ideas.

The danger of the Chemorganiser and teaching in the tutorial classes, means that the students may eventually come to rely more on the tutorial class and the Chemorganiser recipe for understanding, than the large group lecture itself. Whereas I have the opinion that both are of value, the one is meant to compliment the other. The large group lecture for being given the knowledge and the tutorial classes for them to quickly get to doing tutorial problems and thus cement the concept. We as tutors should be there to look over their shoulders, if they are getting the concept wrong, who in the group can get it correct, and show the others? If no one gets it, then we teach a bit. (Though I do find myself looking over shoulders and correcting students, when I see they are going wrong).

(The problem with the large group lectures, being a double, who can concentrate for more than 45 minutes? - but then we are digressing).

Hope my comments are helpful.
Kind Regards,
John

Dear Researcher,

POGIL- the group dynamics. Certainly most of the students seemed to engage in the process, only 2 of the whole class seemed a little dubious. Certainly there was good in engagement in the process.

I think it was a fairly productive way of using their time to gain and share with each other[19], an understanding of, in this case, the limiting reagent.

Did they enjoy it, yes, I think most did[30]. Perhaps the fastest ones in a group may get bored, but they could alleviate that by teaching some of their slower peers[1].

Work ethics- by rotating positions, for each class, it does seem to demand a good work ethic.

Are they learning? I'd say they are getting a different way of learning, I think it is a good way to get concepts across[9].

Chemorganiser- yes, most students did seem to be looking at the Chemorganiser. The class was pretty quiet[23] when you went over the example on the board. Not ALL students were using it.

It did seem to polish what they had learnt in the big group lectures, speaking to two or three students.

Student enjoyment- I'd say they appreciated the new angle, more notes on the topic[35], from a different person to their large group lecturer.

Students were pairing up and some were discussing the subject. It felt more like there was a revised recipe for them to follow,

I would say there was learning there, I don't know if there was the same level[13] in group teaching of the other course?

Hope my comments are useful.
Sorry I did not get to see another session of each,
Kind Regards
John

EXTERNAL OBSERVATION IN THE LATER STAGES OF INTERVENTIONS – YEAR 1

Ms Mundy invited me to participate as an external observer of POGIL and Chemorganiser sessions which form part of her on-going research. The sessions I observed were the second last sessions in the series for both groups participating in the research. The POGIL session took place on 17/10/2013 at 10:00, while the Chemorganiser session took place on 17/10/2013 at 12:00.

With regards to my observations of the POGIL and Chemorganiser sessions I focused on the following aspects: Group dynamics (POGIL), student work ethic, student learning, productive use of time, tool use (Chemorganiser) and overall student enjoyment. I also took the opportunity to have small discussions with the students to gain an understanding of their insight as well as feelings towards the method they were being exposed to.

POGIL

This method makes use of an extensive worksheet, which allows groups of students to discover the key concepts of the topic (in this session it was Redox reactions and oxidation numbers). By working in groups they are able to pool their current knowledge and hopefully expand on it by means of peer-based teaching in order to complete the worksheet in the allocated time.

My initial impression of the session was that it took some time for the students to sort into groups, followed by some more time to settle down and actually start working[20]. I found that group dynamics was a very big problem as it was difficult to get all the group members to participate and make valuable contributions. I also noticed that in all the groups there was only one person actually doing the work with only occasional input from another member, while the rest of the group members were otherwise occupied by their own private conversations, games on their cellphones etc. Thus accordingly only approximately 25% of the students would have learnt anything from the session, while the other 75% have not learnt much at all[10]. The larger problem is that this points to a serious lack of discipline and poor work ethic among the majority of the students when given the opportunity to work in a more informal environment. Each group member is also assigned a specific role and I found that very often the shy students and the students who do not feel secure about the work strongly dislike having to present the work. Also I think the role of the reflector is questionable as I have to ask; how honest will he/she be about the group, about who worked and who did not and what really took place during the session. It would be interesting to see if my observations agree or disagree with those of the various group reflectors, a question Ms Mundy might be able to answer?

When it comes to the productive use of time, the students battled to use the allocated time well and most failed to complete the worksheet in the time available[21], however this could be due to their lack of discipline as many failed to sit down and actually focus on the work despite Ms Mundy's encouragement. Also once the session is active it is difficult to get the entire class' attention should it be necessary to clarify a concept.

From my discussions with the students I found that the students did not enjoy working in groups[31] and that they did not like the POGIL method. Many of the students felt that it was disorganised/ haphazard and as a result felt very lost and did not know what they were supposed to be doing or how to do it. Almost all the students also found the size of the worksheet and the amount of reading involved a daunting task. It was also mentioned that they felt as if they were not getting enough feedback regarding the work[11], while some felt that they were falling behind the other classes in the program. Many of the students also felt that they were not really learning anything and thought that the session had been a waste of time[32]. Regarding members in the group, the stronger and faster members have a tendency to leave the weaker and slower members behind and as a result majority of the students said that they would prefer to work on their own at their own pace[2]. Another aspect of the group work that came up was that the students sometimes managed to confuse each other to the point that no one in the group understood any more. There was one group of students that admitted they had discipline issues when working in a group and admitted to being lazy when they have to figure something out for themselves.

To conclude all the students I spoke to expressed a strong dislike for group work and did not enjoy the POGIL method. This has generated a very negative attitude towards the group work and POGIL and it has thus resulted in a negative attitude towards chemistry which may be difficult to undo[33].

Chemorganiser

This method makes use of a very brief worksheet known as the tool, which the lecturer works through with the students showing them the key concepts of the topic (in this session it was oxidation numbers). By using the tool as a guideline the students are then able to complete a further set of assigned problems and so improve their knowledge and understanding in the allocated time.

My initial impression of the session was that the students settled down and were ready to work very quickly[24] (especially when compared to the POGIL session). During the initial teaching time and the problem solving time the students were very focused and many students mentioned that they liked being able to follow on the worksheet while the work was being explained. I found that all the students in the class were working on the assigned problems using the Chemorganiser tool and in many instances started asking more in-depth questions targeted at improving knowledge and understanding (this was lacking in the POGIL session). There was much more involvement and interest from the students and many of them realised very quickly when they did not understand something and sought help, while the majority of the students appear to be learning and managing to successfully complete the problems[14].

When it comes to the productive use of time the students used the allocated time very well and most of them managed to complete the work assigned in the time available[25]. This group of students had much better discipline and a very good work ethic as they dedicated themselves to the task at hand. It was also much easier for Ms Mundy to get the entire class' attention when it was required.

From my discussions with the students I found that the students really enjoyed the Chemorganiser style of teaching and this was largely due to how structured and focused it was[36]. Every student I spoke to mentioned how much they liked the structure and organisation. The students felt that it really simplified the concepts and helped them to make better sense of the textbook (which many students thought was too general). Many said the Chemorganiser helped them to structure their thoughts and liked having the annotated example problem, although some felt the example problem could be a bit harder. It was also mentioned that the students liked having the brief summary of the most important concepts to refer to and used it to help them see where they were going wrong. The students also did not find the worksheet so daunting due to its smaller size.

To conclude all the students I spoke to really enjoyed working through the Chemorganiser. This method has generated a very positive atmosphere in the class[37] and a general positive attitude towards chemistry. Another notable aspect of the Chemorganiser was that more work got done in this session than in the POGIL session, yet each session was 50 minutes long.

Thus based on what I have observed I feel that the Chemorganiser style results in much better use of time with much more effective learning taking place than with POGIL, and for students such as those on the extended program who often do lack discipline this would be a much more efficient teaching method.

Thank you for the opportunity to observe these two sessions.

Jane

EXTERNAL OBERSVATION IN THE LATER STAGES OF INTERVENTIONS - YEAR 2

With regards to my observations of the POGIL and Chemorganiser sessions I once again focused on the following aspects : Group dynamics (POGIL), student work ethic/involvement, student learning, productive use of time, tool use (Chemorganiser) and overall student enjoyment. I also took the opportunity to have small discussions with the students to gain an understanding of their insight as well as feelings towards the method they were being exposed to.

POGIL

This method makes use of an extensive investigative worksheet, which allows groups of students to discover the key concepts of the topic (in this session it was limiting reagents). By working in groups they are able to pool their current knowledge and hopefully expand on it by means of peer-based teaching in order to complete the worksheet in the allocated time.

My initial impression of the session was slight dismay as the students gave a collective groan after being told that they would be doing a POGIL session that day. The students then took some time to sort into groups, followed by a little more time to settle down and actually start working. I have to add that this took less time this year than it did in 2013, which I think is because the groups formed were smaller (3 students instead of four) and they were allowed to choose their own groups instead of being allocated a group. I found that group dynamics wasn't as big a problem this year[3] as it was in 2013 although there were some individual situations where it was difficult to get all the group members to participate and make valuable contributions. I also noticed that all the groups went through stages where the entire group was distracted and involved in a conversation about other topics (especially the groups of friends)[22]. This generally occurred when the students thought they were not being observed by myself or Ms Mundy.

Overall there was more participation on all the students part this year than in 2013, although my impression was that they only mastered maybe 50-60% of the work/skills that they should have. The problem is that this still points to a serious lack of discipline and poor work ethic among the majority of the students when given the opportunity to work in a more informal environment as they only feel compelled to work when they think they are being observed. This year group members were allowed to choose the role (manager, recorder, general secretary, time keeper) that they would play in the group. These roles suited the shy and more insecure students a bit better as it did not put unnecessary pressure on them to present[4]. Also the questionable role of reflector from 2013 has been removed. What I did find however is that the students were so focussed on trying to get the questions done in the recommended time they spent a lot of time checking their stop watches on their cellphones (which distracted them) and when time ran out they got a bit flustered.
When it comes to the productive use of time, the students used the allocated time a bit better than what they did in 2013, although many still failed to complete the worksheet in the time available, however this could once again be due to a lack of discipline as they were still easily distracted despite Ms Mundy's encouragement to focus and work. Since the groups were smaller and the venue layout (lecture hall) was different, the session was less rowdy than that of 2013 (larger groups and standard classroom with re-arranged desks) so it was easier to get the entire class' attention when it was necessary to clarify a concept.

From my discussions with the students I found that the students enjoyed working in groups and that they liked POGIL (I thought this a bit contradictory to the groan the students gave at the start)[34]. Many of the students felt that they worked better as a group and liked being able to explain things to each other. The students also said they liked the time management, although I personally think they may have focussed too much on this and not enough on the work. Many of the students felt at this stage that the method was preparing them sufficiently for the tests, although my personal impression was that they were extremely over confident and as a result were underestimating the complexity of the work. This was the opinion of the students before they had written any formal tests on the topic and it would be interesting to know whether their impressions of the method changed after they had written a test and gotten the results back.

To conclude all the students I spoke to seemed to like the group work and enjoyed the POGIL method. They generally had a positive attitude towards the group work and POGIL. I was very concerned about how naive the students appeared about the complexity of the work and how they all seemed to be overestimating themselves[12] and their knowledge of the topic after the session.

Chemorganiser

This method makes use of a very brief worksheet known as the tool, which the lecturer works through with the students showing them the key concepts of the topic (in this session it was limiting reactants). By using the tool as a guideline the students are then able to complete a further set of assigned problems and so improve their knowledge and understanding in the allocated time.

My initial impression of the session was once again that the students settled down and were ready to work very quickly (still quicker than the corresponding POGIL session). During the initial teaching time the students paid very careful attention and were quick to participate and interact with Ms Mundy. During the problem solving time the students remained focused and I found that all the students in the class were working on the assigned problems using the Chemorganiser tool and in many instances started asking more in-depth questions targeted at improving knowledge and understanding[5] (far more questions were asked in this session than in the POGIL session). There was more involvement and interest from the students and many of them realised very quickly when they did not understand something and sought help[15], while the majority of the students appear to be learning and managing to successfully complete the problems. The students also took the time to explain the chemorganiser to each other when they did not completely understand something[6].

When it comes to the productive use of time the students once again used the allocated time very well (just as in 2013) and most of them managed to complete the work assigned in the time available[25]. This group of students were much more disciplined than the POGIL group and their work ethic was much better as they focussed on the task at hand. It was also much easy for Ms Mundy to get the entire class' attention when it was required.

From my discussions with the students I found that the students really enjoyed the Chemorganiser style of teaching and this was once again largely due to how structured and focused it was[36]. Once again every student I spoke to mentioned how much they liked the structure and organisation. The students once again felt that it simplified the concepts, helped them save time as it synthesised all the information into a more condensed form and they liked having a procedure to follow. It was also mentioned that the students liked having the brief summary of the most important concepts to refer to and used it to help them see where they were going wrong. Many of the students felt they would like more exposure to different types of questions, but in this case they were referred to their tutorial books and the problems in their textbooks. Two students specifically mentioned that the Chemorganiser helped them to understand and see where they have been going wrong with a problem/method they have been battling with for most of the year. This was very positive feedback which was great to receive.

To conclude all the students I spoke to enjoyed working through the Chemorganiser. This method has once again generated a very positive atmosphere in the class and a general positive attitude towards chemistry and the topic they were working on. Once again more work got done in the Chemorganiser session than what was done in the POGIL session even though both sessions were 50 minutes long.

Based on the feeling that students like this form of concise summary and that students often battle to draw up their own summaries, I suggested to Ms Mundy that she draw up a blank Chemorganiser (with some basic guidelines) on a simpler concept such as percentage yield and give the students the opportunity to draw up their own Chemorganiser. The idea would be to give the students an opportunity to develop a new skill that could potentially benefit them in their future studies. Ms Mundy should be able to give feedback on this, but it would be interesting to know the results of this exercise.

Thus based on what I have observed over 2013 and 2014 I still feel that the Chemorganiser style results in much better use of time with much more effective learning taking place than with POGIL, and for students such as those on the extended program who often do lack discipline this would be a much more efficient and focussed teaching method.

Thank you for the opportunity to observe these two sessions.
Jane

APPENDIX I

PARTICIPANT OBSERVER: POGIL – YEAR 1

POGIL Day 1 (double tutorial = 100 mins)
Attendance ≈ 100%

Acquainted students with POGIL using an introductory slide show. All of the students agreed to participate in the study by signing consent forms. Moved students to the correct venue. Some students were stressed by absent group members. Two students voiced concerns that POGIL may disadvantage them as they enjoyed the original format of the tutorials. Once class began the students were quieter than usual. Only two of thirteen groups battled with group dynamics. Time management was good.

Pleasantly surprised by how well the students took to the intervention and by student productivity. Perhaps this is because students are out of their "comfort-zones" and are now able to excel? Debating having students complete the worksheets using a space provided instead of working in loose paper.

POGIL Day 2 (single tutorial = 50 mins)
Attendance ≈ 80%

Students appeared demotivated after a test the previous day. Some groups only had two members instead of 4. Some students arrived late. About a third of the worksheet was left unfinished. One group tried to sub-divide tasks instead of working as a group, frustration of stronger group member was apparent. Two other strong students complained about the challenges of group work. Students were still unsure about the concept of molar mass at the end of the tutorial despite working through the POGIL worksheet.

Results are not optimal when there are absentees but late-comers do more harm. POGIL requires a large amount of time for students to settle into their roles and start on the tasks, a single tutorial does not seem to be enough time.

POGIL Day 3 (single tutorial = 50 mins)
Attendance ≈ 80%

Still having problems with one group trying to sub-divide tasks. In general students got together quickly and moved at a healthy pace through the Critical Thinking Questions. Students appeared to battle with charge balancing. Towards the end of the lesson students became rowdy and this interfered with the Presenters.

Despite students moving quickly through the work, extra time is needed to "coach" the students in the desired answer format/ layout. This puts increasing strain on the instructor within a single tutorial slot.

POGIL Day 4 (double tutorial = 100 mins)
Attendance ≈ 80%

The venue was doubled-booked so another venue had to be found at short notice. Students arrived up to 30 minutes late. Students were reasonably diligent in the presence of the external observer, John. Groups could have worked through more Critical Thinking Questions, but for the delays. Latter half of the tutorial was used to do worked examples once concepts had been built using POGIL worksheets.

Huge problems are caused when many students are late: groups were shuffled as the members were assumed absent (some groups only had one member at the start of the tutorial) and this caused problems when late students arrived and had to find groups.

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Break: Original tutorial style for two weeks in original venue. Students were informed that POGIL would be restarting and the alternative venue would be used. Many students complained and were unhappy with this news – they did not want to participate in "group work" again.

***

POGIL Day 5 (single tutorial = 50 mins)
Attendance ≈ 65%

Groups were reshuffled based on achievement in a previous test. Many students appeared to resist working in these new groups despite encouragement from the instructor and the presence of the external observer, Jane. Students took a long time to settle into group seating. The minority of students did the work without the help of their peers. The session was noisy.

This was an embarrassing session to have viewed externally as there was a rebellious air during the tutorial. The low attendance implies students decided of their own accord to stop participating, despite having agreed to participate in the study. This created a large amount of worry for the instructor who does not want to drive away or disadvantage students.

POGIL Day 6 (double tutorial = 100 mins)
Attendance ≈ 40%

Attendance was so poor that it was decided that students may form their own groups and allocate their own roles. Students were dull and demotivated despite being warned of the importance of Redox reactions in the syllabus. Students battled to use the POGIL worksheets even though they were the most explicit for this section and required the very little independent concept development. Students lagged and needed constant encouragement. Many answers and explanations were required from the instructor.

There was a sense of gloom and depression; students appeared to have given up although a few still worked doggedly through the exercises. The situation was highly stressful for the instructor and confusing as the resources were simplified and should have been easier for the students to work with.

PARTICIPANT OBSERVER: Chemorganiser – YEAR 1

Chemorganiser Day 1 (single tutorial = 50 mins)
Attendance ≈ 90%

The tutorial began with an introductory presentation on Chemorganisers and letters of consent. Handed out "The Mole Concept" Chemorganiser, went through the basics of how to use it as a learning tool. Each student received a copy to look at and use in their own time. The entire group appeared enthusiastic about Chemorganisers, one weak student asking for more Chemorganisers on the other themes within the syllabus.

Pleased by a good reception of the Chemorganiser. Would like to give out more materials but I do not have the time to edit them, also not sure about distributing Chemorganisers outside of the scope of the study, concerned about ethical implications and unfair advantages.

Chemorganiser Day 2 (single tutorial = 50 mins)
Attendance ≈ 90%

The setup of the data projector was problematic, class time was reduced. The use of the Stoichiometry Chemorganiser was discussed step-by-step with students. Students battled with balancing a chemical reaction. Students tried to use the Chemorganiser to complete the prescribed tasks but were slow.

Using a data projector to explain the tool has slight disadvantages such as lighting and unanticipated technical difficulties, however, it is an effective visual means. Student appeared concerned by upcoming semester test.

Chemorganiser Day 3 (single tutorial = 50 mins)
Attendance ≈ 75%

The Limiting Reagent Chemorganiser was discussed for 20 minutes with students. Students attempted a challenging task with the Chemorganiser, queried and a class discussion was initiated. Afterwards it was evident that most students had grasped and solidified necessary concepts. Students took advantage of presence of the external observer, John, and attempted to seek help from him.

I am happy with how the tutorial went and with the behaviour of the students. The structure provided by the Chemorganiser was useful from and instructor's perspective.

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Break: Original tutorial style for two weeks. Students missed the Chemorganisers, asked when we would use them again.

***

Chemorganiser Day 4 (single tutorial = 50 mins)
Attendance ≈ 80%

Students participated in the discussion of the Oxidation Numbers Chemorganiser and asked questions during the discussion. Students worked diligently on the prescribed problems, naturally forming pairs. Most of the students used the Chemorganiser and used it proficiently. The time allocated was adequate; some students had time to begin homework problems during the tutorial. Students were unperturbed by the presence of the external observer, Jane.

Students appear to be more comfortable with the use of the Chemorganiser, now that they have been exposed to it several times. The students' work ethic and behaviour was [leasing in light of external observation.

Chemorganiser Day 5 and Day 6 (single tutorial = 50 mins)
Attendance ≈ 80%

Balancing Redox reactions in acidic and basic media was dealt with in the last two days of the intervention. Students were appreciative of the neat and explicit steps provided in the Chemorganiser and relied heavily on the use of the Chemorganisers for the prescribed exercises. In some instances students were referring back to the Oxidation Numbers Chemorganiser. Students completed the tasks within the time allocated.

No further technical difficulties were experienced when using the data projector. Despite the semester drawing to a close, class attendance is pleasing. Morale of the class appears high. Slightly concerned that the students may be relying too heavily on the Chemorganiser and will not be able to perform well without it in assessments.