School of Molecular and Life Sciences

Process Oriented Guided Inquiry Learning in Australian secondary science classrooms

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To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number RD-56-12.

Aneeta Dogra
31st March 2021

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ॐ भूर्भुवः स्वः तत्सवितुर्वरेण्यं भर्गो देवस्य धीमहि धियो यो नः प्रचोदयात् ॥

This dissertation is dedicated to my mother, Surindera Raizada and my late father, Baldev Singh Raizada, who always guided and supported me in my ambitions. I would also like to acknowledge my late mother-in-law, Mathi Dogra and my late father-in-law, Nand Ram Dogra for their blessings.

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Abstract

Process Oriented Guided Inquiry Learning (POGIL) is a student-centered pedagogy that can be defined as a hybrid of three learning theories — active learning, inquiry-based learning and constructivism. Its origin in tertiary chemistry classes was borne from the dissatisfaction with the prevalent teacher-centred paradigm of chemistry instruction. The success of POGIL in the United States of America has seen its uptake in many countries, including in Australian universities. However, there is little research on the use of POGIL in secondary chemistry classrooms, and none in lower secondary classrooms.

The study investigated if POGIL can be adapted within the Australian curriculum for upper secondary chemistry and lower secondary science classrooms to address specific science inquiry skills within this curriculum, and whether this implementation would aid in its cross-cultural transferability. The study utilised action research in the teacher as a researcher model and applied quasi-experimental mixed-methods to identify key positive cognitive and affective gains in the POGIL classroom.

The participants in the study were Year 8 (n = 100) and Year 11 Chemistry (n = 33) students enrolled at a public secondary school in a metropolitan area of Perth, Western Australia. For the purpose of triangulation, both quantitative and qualitative data were collected through pre- and post-tests, reflection sheets, teacher observations and semi-structured interviews. The Year 8 study involved an experimental group (POGIL) and control group (traditional) whereas the Year 11 study had only an exploratory group without a control group.

The research demonstrated the efficacy of POGIL in meeting curricular goals, like scientific inquiry, on a number of learning environments and affective dimensions. The Australian science curriculum and POGIL process skills were found to be aligned with each other, with some skills (eg. communication, problem solving and critical thinking skills) common to both. POGIL serves as an effective tool because it targets both content knowledge and process skills. Following an in-depth multi-dimensional analysis of data, it can be concluded that students recognised the benefits of cooperative learning and guided inquiry, the two key constituents of a POGIL class. This study has made distinctive contributions to POGIL and chemistry education in Australian schools, being the first attempt to investigate the efficacy of POGIL in Australian secondary schools' chemistry classes and supports further implementation of POGIL in these settings.

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Glossary

ABCI Acid-Base Reactions Concept Inventory

ACARA Australian Curriculum, Assessment and Reporting Authority

ACER Australian Council for Educational Research

ANOVA Analysis of Variance

ASCIv2 Attitude towards the Subject of Chemistry Inventory, version 2

CI Confidence Interval

CUCEI College and University Classroom Environment Inventory

EAL English as an Additional Language

HREC Human Research Ethics Committee

LB Lower Bound

M Mean

PBL Problem-Based Learning

PLTL Peer-Led Team Learning

POGIL Process Oriented Guided Inquiry Learning

PTDI Particle Theory Diagnostic Instrument

SCSA School Curriculum and Standards Authority

SD Standard Deviation

SES Socioeconomic status

SHE Science as a Human Endeavour

SII Strengths, areas for Improvement, and Insights

SIS Science Inquiry Skills

SLEI Science Laboratory Environment Inventory

STEM Science, Technology, Engineering and Mathematics

SU Science Understanding

TORCH Test of Reading Comprehension

TIMSS Trends in International Mathematics and Science Study

UB Upper Bound

ZPD Zone of proximal development

Chapter 1

Thesis Introduction

1.1 Introduction

The primary aim of this action research study is to evaluate the efficacy of Process Oriented Guided Inquiry Learning (POGIL) in Australian lower and upper secondary science classes and to demonstrate its cross-cultural utility. The researcher drew on her personal experiences as a teacher to create and evaluate a student-centered constructivist classroom environment in an Australian senior high school, while students were learning chemistry concepts.

This chapter presents the origin of the research problem, the importance of this study and attends to:

- the background to the problem describing the reason why many students find science, and in particular chemistry, hard to understand (Section 1.2);
- the key research questions explored during this research study (Section 1.3);
- insights on the significance of the research study (Section 1.4);
- the research design highlighting the research questions (Section 1.5), and;
- the limitations of this study (Section 1.6).

The chapter concludes with the definitions and terminologies used in this thesis (Section 1.7) and an overview and organisation of the thesis (Section 1.8).

1.2 Requirement of today's world

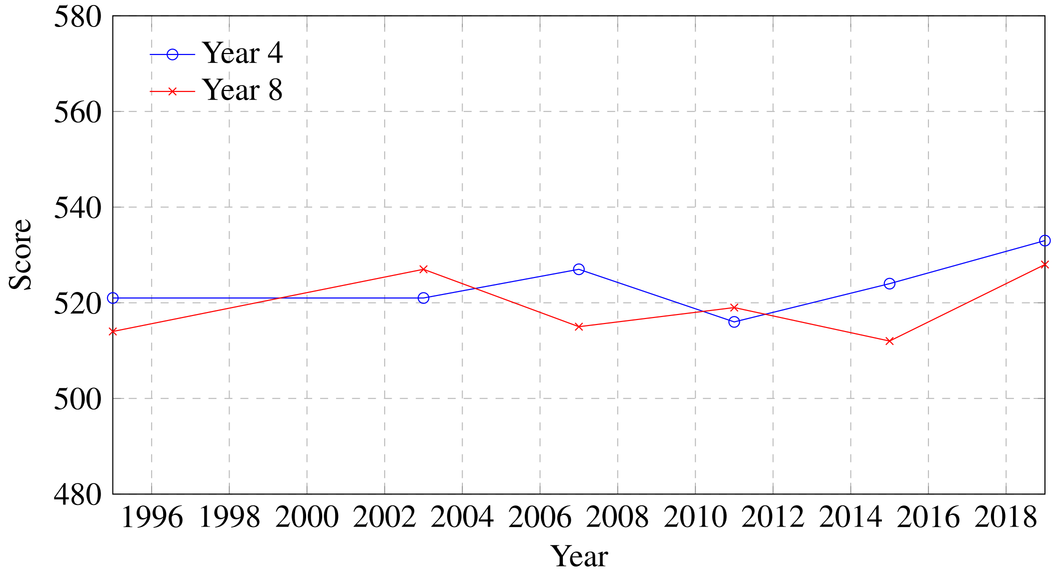
It is predicted that in the near future an estimated 75% of all new jobs will require qualifications and competency in the areas of Science, Technology, Engineering and Mathematics (STEM) (Acker, 1996; Hogan & Down, 2016). Compounded with this scenario are reports, which suggest that there will be a shortage of STEM professionals globally (Panizzon et al., 2015; Reeve, 2016; Siekmann & Korbel, 2016). In today's competitive world, our society needs individuals who not only have content-based knowledge, but also possess other essential skills such as critical and analytical thinking, the ability to collaborate, and conduct information processing and analysis (De Broucker et al., 2001; Doolittle & Camp, 1999; Kivunja, 2014; Pompa, 2015; Rice & Wilson, 1999).

In this context, education plays a significant role. The responsibility lies upon the education system to assist in shaping individuals to have strong foundation skills in science and mathematics and be ready to face the challenges of the 21st century (Taylor, 2016). However, many studies have documented a general decline towards taking science subjects in school, and the majority of students choose not to continue studying science past the point at which it is no longer compulsory (Barmby et al., 2008; Bennett, 2001; Lindahl, 2003; Potvin & Hasni, 2014). According to Boedo (1992) many students do not perform well in science and mathematics as they develop a 'thinking gap' due to a lack of higher thinking capabilities, which is a delay in the growth of human rational capacities to meet the evergrowing demands of a progressively complex world. Educators can play an important role in closing this gap to foster students' interest and understanding in these subjects.

1.2.1 Student learning difficulties in science

Several secondary students have demonstrated a negative attitude towards science because they find it uninteresting and do not see its relevance in their lives (Lyons, 2006; Naidoo, 2010; Yager & Yager, 1985). In an analysis study, Osborne et al. (2003) found that from the age of 11 onwards, students' attitudes and interest towards science declines, and that this decline begins during the primary to secondary transition phase (Braund & Driver, 2005; Potvin & Hasni, 2014).

Similar to many countries, Australia is no exception and many studies have supported this general decline towards science at a secondary school level in Australia (Hassan, 2008; Hassan & Treagust, 2003; Lyons et al., 2003). The Australian Government and school administrators' are very concerned (Baker, 2019; Ey, 2012) with the achievement results in science as measured by the 2015 Trends in International Mathematics and Science Study (TIMSS) study, in which more than 60 countries from all over the world participated (Thomson et al., 2016). In this study, under the responsibility of the Australian Council for Educational Research (ACER), more than 570 Australian schools and 16,000 Year 4 and Year 8 students participated. The TIMSS report published in 2016 by ACER (Thomson et al., 2016) has indicated that the performance of Australian students in science and mathematics has stagnated for the past 20 years, with only Year 4 mathematics students scoring slightly higher as compared to their counterparts in 1995. The results for Australia from 1995 to 2019 is given in Figure 1.1.



Note: No data is available for the year 1999

Figure 1.1: TIMSS science results for Australia from 1995 to 2019 (Thomson, Wernert, O'Grady, et al., 2020)

The report shows that during 1995 and 2015, high performing countries such as Singapore, Japan, Korea, Hong Kong, and Chinese Taipei continue to make strong progress, whereas anglophone countries such as England, Canada, United States and Ireland have improved relative to Australia falling behind. Students in other high performing countries outperformed Australian Year 4 and Year 8 grade students. This outcome is of great concern because in a globalised economy, nations whose population is well-equipped with knowledge and skills will have a competitive advantage, and Australia risks falling behind (Hassan & Treagust, 2003). The report stresses the need to focus on long term co-ordinated strategies to address the issue of the declining interest of students in science.

However, in the 2019 TIMSS study (Thomson, Wernert, Buckley, et al., 2020), Australia's mean score increased for both Year 4 and Year 8 science. The results for Australia from 1995 to 2019 is given in Figure 1.1. In this study, 571 Australian schools with 14,950 students participated. The report shows that although Australia has come par with countries including the US, England, Hong Kong and Ireland it is still behind Singapore, Korea, Russia, Japan, Chinese Taipei, Finland, Latvia and Norway. The report acknowledged that students' poor performance is mainly due to socioeconomic background and lack of opportunities and resources.

1.2.2 Learning difficulties in chemistry

As reported by Johnstone (2000) and Taber (2001), the majority of teachers and students find that chemistry is one of the most demanding and difficult courses in secondary school because it depends on perceiving the invisible and imperceptible world. It has been reported that students who have a hostile experience with chemistry in secondary school will develop anxiety which affects their performance adversely (Abendroth & Friedman, 1983; Berdonosov et al., 1999; Eddy, 2000). The abstract and complex nature of chemistry has its consequences for the teaching of chemistry (Gabel, 1999) and if these abstract concepts are not fully understood, learners will struggle to understand the further theories and concepts related to it (Coll & Treagust, 2002; Nicoll, 2001).

Many researchers believe that active student participation and social interaction is likely to keep students engaged and increase student satisfaction (Lewis & Lewis, 2005, 2008). This student engagement is also less likely to induce surface approaches to learning (Gow & Kember, 1993), thus fostering a deeper understanding of scientific concepts and longer retention of knowledge. Teachers are aware of these problems encountered by their students but they fail to address them because they believe that the problem may lie within the dominant teacher-centred pedagogy in chemistry. This researcher, being a science teacher with a specialisation in chemistry, has also noted that many students do not continue to study chemistry in secondary schools and even the brightest students struggle to understand the abstract concepts in chemistry. Teachers need to explore new ways to overcome these issues.

As claimed by Lin (2003), educational institutions should promote and establish student-centred learning environments to engage students. Science educators use many research-based pedagogies of engagement (Raker et al., 2021), comprising of Problem-Based Learning (PBL), POGIL, and Peer-Led Team Learning (PLTL) in their classrooms with few discrepancies among them (Eberlein et al., 2008). Many studies support the claim that inquiry-based learning promotes students' interest, attitude and achievement in science (Ali & Awan, 2013; Dhindsa & Chung, 2003; Papanastasiou & Zembylas, 2002). Inquiry-based learning helps students to become independent learners with educators acting as facilitators. As mentioned by Kahn and O'Rourke (2005), inquiry-based learning can help to address current concerns and needs for student learning, while providing the flexibility for the development of a wide range of student abilities.

Since 1960, many guided inquiry-based student-centred instructional models supported by constructivism and related to the theories of Piaget and Vygotsky have evolved to enhance students' understanding of abstract concepts. POGIL has emerged as an important non-traditional teaching method in the 21st century (Brown, 2010a; Farrell et al., 1999), enabling guided inquiry student-centred instructional pedagogies which provide opportunities to teach both content and key process skills simultaneously. As described by Moog et al. (2009), "POGIL is an interactive process of thinking carefully, discussing ideas, refining understanding, practicing skills, reflecting on progress, and assessing performance".

In a POGIL classroom, students actively engage in small self-managed groups to explore a concept by working on specially designed guided inquiry exercises, which provide data and information to the students (Spencer & Moog, 2008). In this process, the teacher serves as a facilitator who guides students periodically when the need arises (Hanson, 2013). Several research studies have proven the positive impact of POGIL on students' academic achievement (Brown, 2010a; Brown, 2010b; Soltis et al., 2015) and their attitude towards learning (Hale & Mullen, 2009; Shatila, 2007; Vishnumolakala, 2013) at a tertiary level as well as at a secondary level (Barthlow, 2011). However, no study has reported using POGIL at a secondary level in Australia.

1.3 Research questions

This research study seeks to evaluate the efficacy of POGIL as a student-centred pedagogy for use in Australian secondary science classes while studying chemistry concepts. The study attempts to answer the following research questions.

Research question 1

Is POGIL a good match with the existing intended Australian science curriculum?

The intended curriculum for the present study is the Australian science curriculum developed by the Australian Curriculum, Assessment and Reporting Authority (ACARA). The Australian Curriculum for Year 8 science and Year 11 chemistry will be analysed to see if POGIL is a good match with the existing Australian curriculum. In the Australian science curriculum, there is particular stress on Science Inquiry Skills (SIS) and and Science Understanding (SU). In addition to this, it requires teachers to incorporate general capabilities into their teaching depending on their choice of activities and individual learning needs of their students. The present research will investigate how POGIL might address these skills.

Research question 2

Is there any evidence that POGIL is culturally transferable to an Australian science classroom and can be implemented to address its curriculum?

Australia is a multicultural country and its classrooms have broad ethnic and linguistic diversity, with many students who have English as their second language. Further, in this particular context the school where the research takes place is in a low socio-economic area with ensuing factors such as behaviour management, academic ability and attendance that are enough to challenge any classroom teacher. Many countries, including Australia, have successfully implemented the POGIL pedagogy at the tertiary level (Bedgood et al., 2010). The current study explores how the Australian science curriculum can be implemented in Australian secondary classrooms using the POGIL pedagogy and collects evidence to support its claim. The quantitative and qualitative data will be collected using teachers' observation, students' reflection sheets and semi-structured interviews to inform the implementation of this pedagogy.

Research question 3

Are there any differences in students' achievement in selected diagnostic tests and school-based tests in chemistry after the teaching intervention?

The present study uses a quasi-experimental design (Mitchell & Jolley, 2010) by utilising diagnostic tools with strong evidence of their reliability and validity, such as the Particle Theory Diagnostic Instrument (PTDI) (Treagust et al., 2011), Acid-Base Reactions Concept Inventory (ABCI) (Jensen, 2013) and normal classroom assessments. The research will investigate if there are any statistically significant differences in students' achievement on these tests after the POGIL intervention.

Research question 4

What are students' perceptions about the POGIL lessons?

Individuals' motivation to learn is influenced by their perceptions of learning. According to Fraser and Fisher (1982) there is a strong link between students outcomes and their perceptions of the learning environment. In the present study, students' perceptions about the POGIL pedagogy will be measured using instruments with strong evidence of their reliability and validity, such as the Science Laboratory Environment Inventory (SLEI) (Fraser et al., 1993), Attitude towards the Subject of Chemistry Inventory, version 2 (ASCIv2) (Bauer, 2008; Vishnumolakala et al., 2017) and College and University Classroom Environment Inventory (CUCEI) (Treagust & Fraser, 1986). As one group involved in this study is an upper secondary chemistry class, researcher decided to use CUCEI in this class and SLEI in the lower secondary class. This matter will be discussed in Chapter 3. In addition, qualitative data will be collected using teacher's observations, students' reflection sheets and semi-structured interviews.

1.4 Significance

POGIL originated from the United States of America in 1994, and up until now, there are more than 1000 educators who have successfully implemented POGIL in various subjects both at secondary and tertiary levels (POGIL, 2019). In Australia, the use of guided-inquiry methods such as POGIL have been limited to the tertiary level only. Active learning in science at a tertiary level has strong proponents by a collaborative project between six major universities of Australia with the main purpose to promote excellence in higher education (Bedgood et al., 2010). The final report emphasised the importance of POGIL in improving the students' performance in the participating institutions.

The current study is an action research study conducted by the researcher as a science teacher to explore the results of the implementation of POGIL in the secondary classroom. This study is significant for many reasons. The proposed study will extend POGIL to an Australian secondary school context. This project aims to develop and adapt learning tools for use in Australian secondary classes and draw from the local experience at the tertiary level, in the development of a leadership model to permit widespread adoption of teaching innovation.

The present study will optimistically contribute to the existing pool of research on the implementation of POGIL in secondary schools as well as help Australian educators choose an effective pedagogy for teaching science. By this research, Australian students can enhance their understanding in these core subjects such as science and mathematics, and when they progress towards university with the required mental framework, they are likely to succeed.

The research study will give insight into Australian secondary school students' perceptions about POGIL and give a sense of direction to many pioneering teachers who continue to implement new strategies and methods to improve the understanding of their students. In addition to this, the results of this study will help educators develop globally-competitive students in the future by fostering new ways of enhancing knowledge, skills and attitude.

And lastly, being a teacher herself, the study will give researcher the opportunity to enhance her professional knowledge by providing her with a chance to successfully write, implement and analyse POGIL activities in her classes.

1.5 Research design

The research study is conducted in three stages. As presented in Figure 1.2, the first stage was the study of the documented curriculum and its alignment with POGIL to address the research questions about the intended curriculum. It also involves construction and selection of relevant POGIL worksheets to be used in the quasi-experimental experiment. This stage provides an overview of how POGIL sessions are implemented in the classrooms.

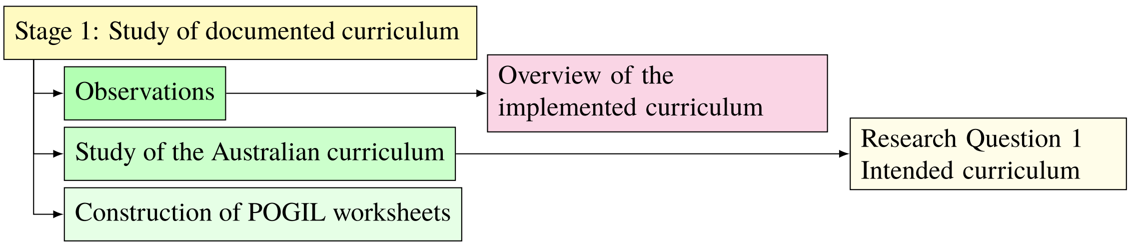


Figure 1.2: First stage of the research process adapted from Widhiyanti (2016)

The second stage is the implementation of POGIL in Year 8 science and Year 11 chemistry classes as shown in Figure 1.3. The Year 8 study consists of three research activities:

1. Alignment and adaptation of Year 8 science curriculum with POGIL to address the first research question about the intended curriculum. It analyses the existing resources so that POGIL skills can be linked with the science inquiry skills. It also addresses the second research question about the implemented curriculum.

2. Administer the SLEI questionnaire (Fraser et al., 1993) and ASCIv2 survey originally developed by Bauer (2008) to find out information about the perceived curriculum.

3. Administer pre-diagnostic test (multiple-choice questions) developed by the teacher to assess students' conceptual understanding.

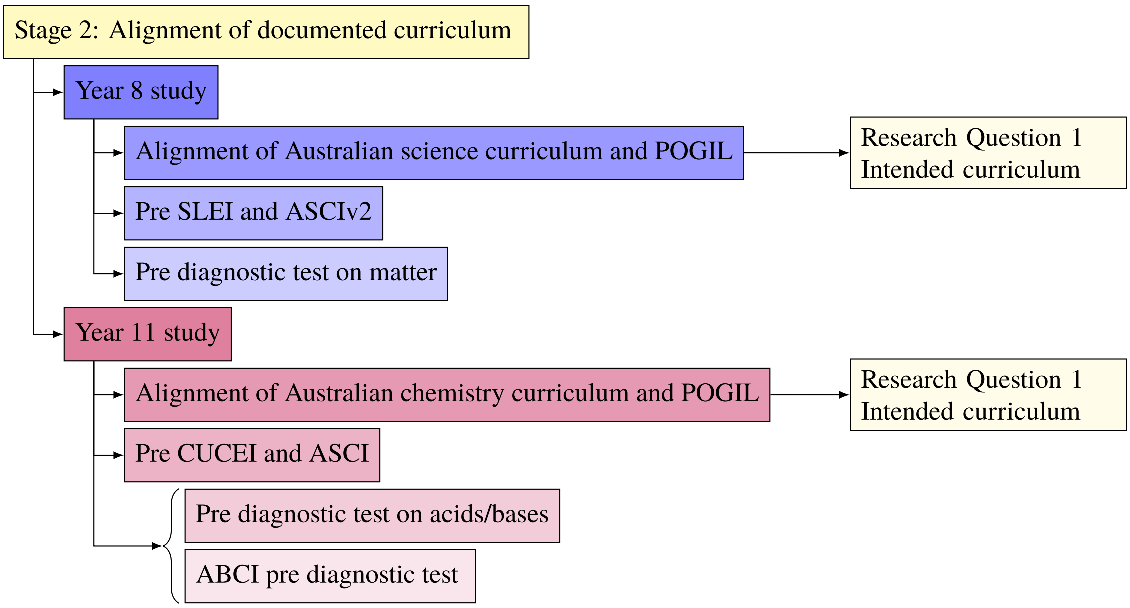


Figure 1.3: Second stage of the research process adapted from Widhiyanti (2016)

The Year 11 study consists of three research activities:

1. Alignment of Year 11 chemistry curriculum with POGIL to answer the second research question about the implemented curriculum.

2. Administer pre-diagnostic test (multiple-choice questions) and ABCI, a two tier instrument developed by Jensen (2013).

3. Administer the ASCIv2 survey and CUCEI questionnaire developed by Fraser et al. (1986)

The final stage is the implementation of the POGIL pedagogy in Year 8 science and Year 11 chemistry classes as shown in Figure 1.4. Different tools were used to collect the data to address the research questions about the achieved and perceived curriculum.

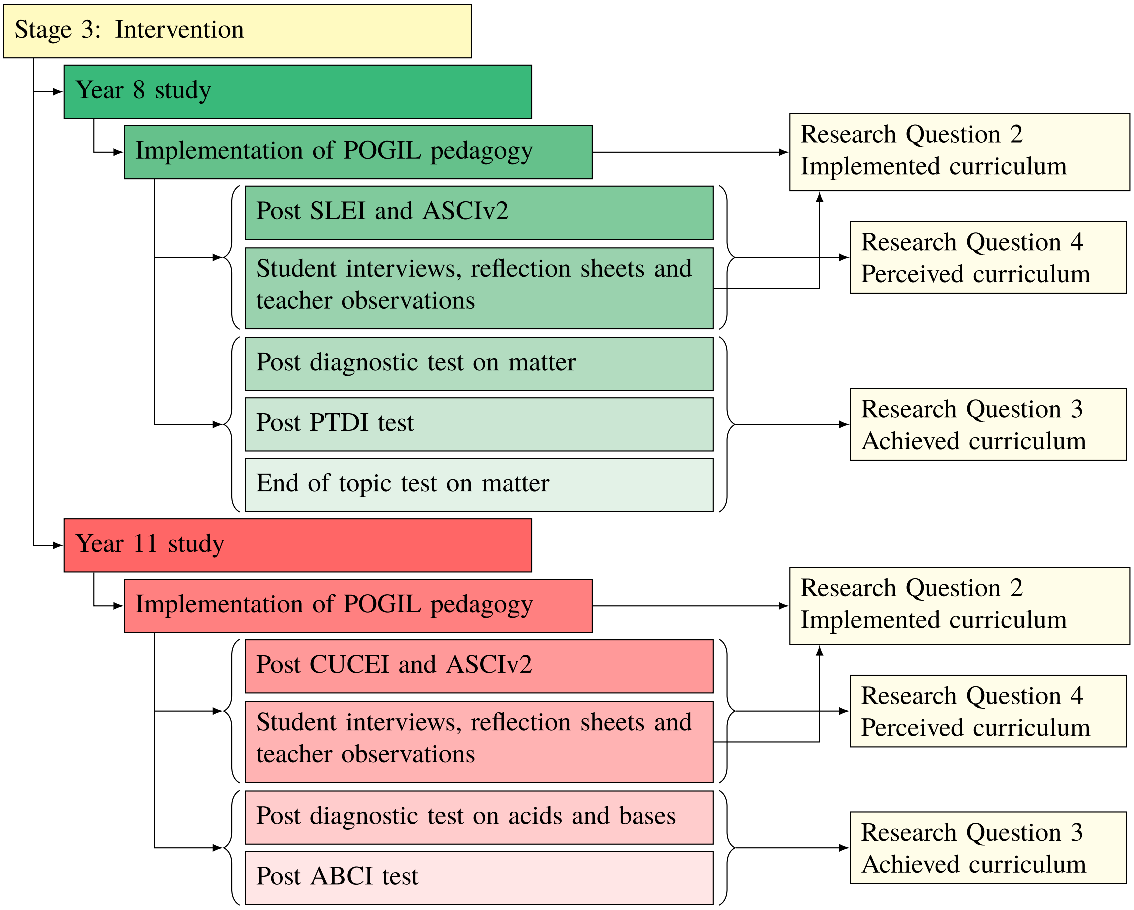


Figure 1.4: Third stage of the research process adapted from Widhiyanti (2016)

The Year 8 study consists of:

1. Administration of a post-diagnostic test (multiple-choice questions), PTDI, a two-tier test on kinetic theory of matter developed by Treagust et al. (2010) and

an end of topic test on matter to assess students' conceptual understanding about matter.

2. Administration of post SLEI and ASCIv2 surveys to investigate students' perceptions about POGIL pedagogy.

3. Additional data collected using students' reflection sheets, classroom observation and interviews.

The Year 11 chemistry study consists of:

1. Administration of post-diagnostic test (multiple-choice questions) and ABCI to assess students' conceptual understanding about acids and bases.

2. Administration of post CUCEI and ASCIv2 surveys to investigate students' perceptions about POGIL pedagogy.

3. Additional qualitative data collected using students' reflection sheets, classroom observation and interviews.

The stages involved in this research design clearly show that this research uses both qualitative and quantitative methods of data collection. The methodologies applied in this study will be reviewed in detail in Chapter 3.

1.6 Limitations of this study

This study has some limitations as discussed below.

- The sample size was limited by the size of the classes selected for this study. For the Year 8 study, only two classes were selected, one was the experimental group taught by the researcher and the other was the control group taught by an experienced science teacher. For the Year 11 study, there was only one chemistry class with 16 students in the first cycle (2013), and 17 students in the second cycle (2015).

- There may be some pre-existing differences between different groups due to the fixed nature of educational settings.
- The researcher relied on all students to answer all questions thoughtfully and truthfully.

1.7 Definitions and terminology

Process Oriented Guided Inquiry Learning (POGIL): A student-centred pedagogy in which students in small groups are engaged in a learning cycle of activities that intend to develop content knowledge and process skills (Spencer & Moog, 2008).

Curriculum: An interrelated set of plans and experiences which a student completes under the guidance of the school (Marcs & Willis, 2007, p. 93).

Intended curriculum: Consists of guidelines that summarise the curriculum that teachers are expected to teach to the students (Porter & Smithson, 2001).

Implemented curriculum: Is the operational or taught curriculum (Cuban, 1993).

Perceived curriculum: The curriculum as interpreted by the learner (Van den Akker, 1997).

Achieved curriculum: Also known as the attained curriculum, it shows students' academic achievement and attitude (Cuban, 1993; Van den Akker, 1997).

Zone of proximal development (ZPD): Is the cognitive distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers (Vygotsky, 1981).

Cooperative learning: Students work in small groups and each member of the group is assigned a specific role and every one participates to achieve the final goal (Adams, 2000).

1.8 Overview of the thesis

This action research study implemented a mixed-methods design to evaluate the efficacy of POGIL, a student centred pedagogy, in Australian secondary science classes and to demonstrate its cross-cultural utility. Two distinct studies were conducted over a period of three and half years, involving students from different cohorts and year levels. The first study involved two Year 8 classes and the second study involved one Year 11 chemistry class from a senior high school located in the Perth metropolitan area. The present thesis has been organised into seven chapters and its content is organised as follows:

Chapter 1 briefly describes the research problem, its origin, the significance of this research and definitions of some key word used in this study.

Chapter 2 is dedicated to the literature review, which examines the previous work conducted in this field of research. This chapter starts with an introduction and leads to the discussion of the curriculum and theoretical frameworks required for this study. The chapter presents reviews on different cognitive models of learning and how the human brain processes information. It focuses on the importance of students' perceptions about the learning environment and methodologies used for investigating students' understanding of concepts. The chapter ends with a discussion of core concepts of the Australian curriculum and the significance of an action research method.

Chapter 3 is devoted to the research methodology used in this study. This is an action research study and implements a mixed method approach. The chapter begins with a general description of the research design, ethical consideration, data collection tools for both qualitative and quantitative data, and details of instruments and their validity and reliability.

Chapter 4 addresses the first two research questions concerning the intended and implemented curriculum. Relevant information regarding the intended curriculum for the Year 8 chemical sciences and the Year 11 chemistry course is presented. It also addresses the second research question and describes how the learning requirements were implemented as part of the curriculum. The chapter ends with the researchers' classroom observations and the students' reflection about the POGIL interactions.

Chapter 5 focuses on the achieved and perceived curriculum about the Year 8 study. The first half of this chapter addresses the third research question and explores the Year 8 student's conceptual understanding. The results of the data analysis regarding the student's understanding of chemical sciences are presented. The second half of chapter 5 focuses on the fourth research question and explores the students' perceptions about the POGIL learning environment. The results of the data analysis regarding the students' perceptions of their learning gains are also presented.

Chapter 6 is devoted to the achieved and perceived curriculum in regard to the Year 11 study. It addresses the third research question and explores the Year 11 students' conceptual understanding. The data regarding the students' understanding of chemistry are presented and analysed. This chapter also focuses on the fourth research question and investigates the students' perceptions about the POGIL learning environment. The chapter ends with a discussion regarding the results of the data analysis in reference to the students' perceptions of their learning gains.

Chapter 7 focuses on the conclusion and implications for future research. The limitations of the present study and suggestions for future research are discussed in this chapter.

Chapter 2

Literature Review

2.1 Introduction

In this chapter, the researcher will examine the literature applicable to this research study with an emphasis on POGIL as a method to develop students' critical thinking and communication skills while keeping them actively engaged in the learning process. An outline of the previous research on POGIL is presented with an aim to provide direction and critical analysis of the data collection instruments and reviews the literature pertaining to students understanding of science, particularly in the context of chemistry (Section 2.2). A theoretical framework is necessary to support the theory of a research study. The chapter presents discussion of constructivism, social constructivism and information processing approach for cognitive development as well as the influence of learning environment and attitudes on student outcomes (Section 2.3).

Social constructivism emphasises the importance of social interaction in the development of cognitive knowledge and is supported by many pedagogies, such as active learning, inquiry learning and cooperative learning. POGIL is based on social constructivism and the cognitive model of learning. The present chapter highlights the research that supports the effectiveness and implementation of POGIL in the classrooms (Section 2.4) and particularly in the Australian classrooms (Section 2.5). In social sciences, action research plays an important role to encourage individuals' and institution's development (Section 2.6). Studies employing POGIL in topics related to the Year 8 and Year 11 study are presented in Section 2.7. The literature related to the curriculum framework embraced for this research study is reviewed in Section 2.8. Finally, Section 2.9 reviews literature related to the Australian Curriculum and its core concepts followed by the main points of this chapter (Section 2.10).

2.2 Learning of science

We depend on science to provide new knowledge, technology and solutions to persistent world problems (Goodrum & Rennie, 2007), and educators must raise students' interest in science and technology studies (Hassan & Treagust, 2003). However, many students become dissatisfied with science upon entering high school and find science irrelevant and boring (Rennie et al., 2001). Various factors contribute to students' lack of interest in science. Tytler (2016) argued that Australia's performance in school science international assessments has gradually declined due to ineffective traditional teaching practices, resulting in students not actively participating in the subject. Students' motivation plays an important role in fostering a deep understanding and induces conceptual change thus enhancing their academic achievement in science (Bryan et al., 2011). It has been widely established that to develop students' long term interest in science, they must have a positive attitude towards science which is linked to the level of motivation they bring with them into the classroom (Oroujlou & Vahedi, 2011). This issue is further discussed in detail in Section 2.3.4 of this chapter.

2.2.1 Student understanding of chemistry

Chemistry is considered a difficult subject to learn and teach by both students and teachers (Johnstone, 2000). According to Gabel (1999), the way chemistry is taught and its language has made the understanding of chemistry very difficult. The study of chemistry involves three levels of chemical representation — macroscopic, sub-microscopic or particulate, and symbolic or representational level, known as the "chemistry triangle" (Johnstone, 2006) as represented in Figure 2.1. An individual needs to understand the link between all three levels in order to understand chemistry (Ebenezer, 2001; Gabel, 1999; Harrison & Treagust, 2000; Raviolo, 2001) and this lack of understanding may create difficulties for students to apply their knowledge to solve problems.

The macroscopic level is measurable and real, so a majority of the students can understand it (Johnstone, 2006). At the macroscopic level, properties can be observed

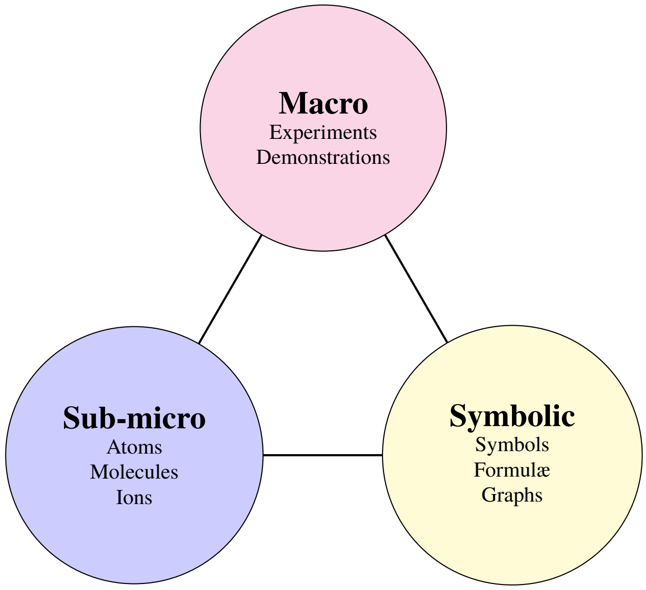


Figure 2.1: Johnstone's three conceptual levels of chemistry

such as changes in colour, shape and size and it includes experimental chemistry. For example, students can observe that water can exist in all three states of matter—solid, liquid and gas and when we add or remove heat energy it can change from one state of matter to another. The particulate level or sub-microscopic level is also real but it is abstract, and cannot be seen which creates problems for many students (Johnstone, 2006). At the sub-microscopic level, properties cannot be observed because they occur at a particulate level as atoms, ions or molecules etc. which are too small to be observed. For example, students cannot see that when the temperature is raised, how the attractive forces between the molecules are overcome and they move apart changing solid ice into liquid water and then into a gaseous form. The third level is representational which involves symbols, figures, formulas, models and graphs etc. of the macroscopic and sub-microscopic level (Johnstone, 2006). The intangible nature of chemistry and the requirement for the learner to understand what is happening at the sub-microscopic level makes the use of symbolic representations very important.

Research studies by Yarroch (1985) and Sawrey (1990) have found that many students can answer the chemistry problems correctly without understanding the theoretical knowledge because they rely on remembering concepts with minimal or no intellectual reasoning attached to it. They use algorithms to solve problems, but this creates alternative conceptions (Gabel, 1999). Further Harrison and Treagust (1996) have illustrated that the "negative outcomes arise when students are left to draw their own conclusions about analogical models" leading to alternative conceptions. The analogical models such as Bohr model of the hydrogen atom and the billiard ball analogy for the kinetic theory of gases play an important role in understanding and developing theories (Achinstein, 1964). It is very significant that to comprehend chemistry concepts, a learner should be able to make connections between these three levels. However, as already noted, many students fail to understand chemistry concepts at these three levels which makes chemistry a difficult subject for them (Johnstone, 1991). Research studies have indicated that students and even some teachers fail to interrelate one level to another (Chandrasegaran et al., 2008; Chittleborough & Treagust, 2007; Gabel, 1999; Taber, 2001). Chemical models help us to understand the sub-microscopic level by giving us a perceptible cue. As mentioned by Chittleborough and Treagust (2007) "Chemistry is based on the theory of the particulate nature of matter — the sub-microscopic level of matter — but we 'see' the macroscopic and use models to represent the sub-microscopic levels."

2.3 Theoretical framework

Researchers use a theoretical framework so that they can present their understanding of theories and concepts related to their research study (Ravitch & Carl, 2016). The constructivist philosophy of teaching and learning serve as the theoretical framework for this study. The following sections refer to the theories which serve as a base to the utilisation and implementation of POGIL in classrooms.

2.3.1 Constructivism and social constructivism for cognitive development

The constructivist theory of cognitive development was proposed by Jean Piaget in the early 1970s (Duchesne & McMaugh, 2019) and is based on observation and scientific study. Piaget studied children and their intellectual capacities at different phases of growth. He proposed that there are four stages in human development: the sensorimotor stage, the preoperational stage, the concrete operational stage, and finally the formal operational stage. Knowledge cannot be transferred from the mind of the teacher to the mind of the learner, but rather knowledge is personal and is constructed by learners based on their past experiences (Bodner, 1986). Learning experiences should therefore take into account learners existing knowledge and provide them with opportunities to develop new knowledge by revising and integrating the new knowledge. Prior knowledge plays a very significant part in the students' academic success and cannot be ignored (Dochy et al., 1999; Hailikari et al., 2007; Marzano et al., 2000; Thompson & Zamboanga, 2003).

According to Piaget's model (Piaget, 1972; Piaget & Duckworth, 1970), learning occurs in two stages — assimilation and accommodation. Learners never come to a classroom with a blank state of mind rather they come with already articulated knowledge, concepts, and understandings which becomes their foundation for the new knowledge (Sewell, 2002). When learners come across new knowledge, they try to fit and integrate the new knowledge into the existing one and assimilation of the knowledge occurs. However, sometimes the new knowledge does not fit in the existing knowledge schemata and imbalance occurs which creates alternative conceptions (Acker, 1996) as an individual fails to strike a balance between assimilation and accommodation. Even though many research studies have confirmed the existence of alternative conceptions, many educators fail to recognise them and therefore do not plan to address these issues in their lessons (Gabel, 1999). Effective teaching should help to link the student's preconceptions and the scientific concepts being taught in the classroom (Barke et al., 2009; Bransford et al., 1999; Osborne & Wittrock, 1983). After assimilation, the learners then accommodates the new knowledge to reshape their existing knowledge. Both the assimilation and accommodation of knowledge are important for the academic growth of learners.

According to Blake and Pope (2008), social interaction plays an important role in the student's learning as it is through this that students learn from their peers as well as from adults. Building on Piaget's research, Vygotsky (1981) proposed the social constructivism theory, in which a learning process is influenced by the learner, the teacher and the school (Yager, 1991). A social constructivist classroom is similar to a constructivist classroom with an exception that it is acknowledged that students learn through social interaction. Learning is through collaboration, which is supported by peer interaction and structured by the teacher.

Vygotsky introduced a term known as the zone of proximal development (ZPD) to describe key aspects of social constructivism. ZPD is "the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1981). As depicted in Figure 2.2, every learner has a ZPD where they are most likely to succeed. Anything that is too complex cannot be learned as it is not in their ZPD. Vygotsky suggested that with social interaction such as support from peers and guidance from a mentor, students can understand concepts that they cannot understand on their own. The upper boundaries of ZPD are always changing and as learners grow, they continue to develop their potential thus shifting the ZPD. The constructivist classroom is student-centred because the focus is on the students and not the teacher. Students are actively engaged to learn from peers and appreciate the different viewpoints put forward (Duchesne & McMaugh, 2019).

Vygotsky's theory of cognitive development encourages students' to actively partake in their learning, instead of passively listening to information transmitted from their teacher, which is in line with the traditional method of teaching (Duchesne & McMaugh, 2019). Over the last two decades the constructivist approach, and the teaching strategies associated with it, have been widely recognised. Many research studies have been undertaken which support the positive influence of student-centred constructivist instruction methods on learning (Dethlefs, 2002; Harkness, 2016; Lord, 1997, 1999; Yuen & Hau, 2006). Research has shown that the constructivist approach is more effective for teaching problem solving, intellectual strategies, and interpersonal thinking

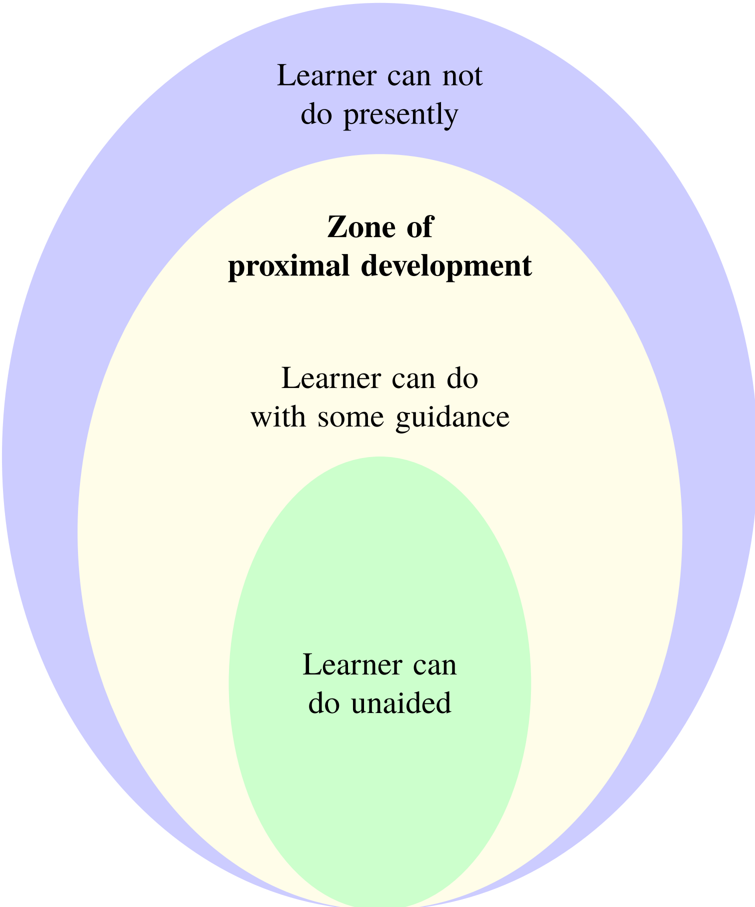


Figure 2.2: Vygotsky zone of proximal development model (Vygotsky, 1981)

(Bonk & Smith, 1998) and also helps to reduce alternative conceptions (Acker, 1996). However, Weeks (2013) stated that using constructivist approach alone cannot eliminate all alternative conceptions in adult learners and some level of guidance is necessary.

2.3.2 Information processing approach to cognitive development

Piaget and Vygotsky explained cognitive development in terms of children's thinking whereas cognitive development can alternatively be explained in terms of children's ability to process information (Duchesne & McMaugh, 2019). Based on the Baddeley (2010) model of information processing, Johnstone (1997, 2000, 2006) proposed a simplified model known as the Information Processing Model in learning chemistry, which is summarised in Figure 2.3.

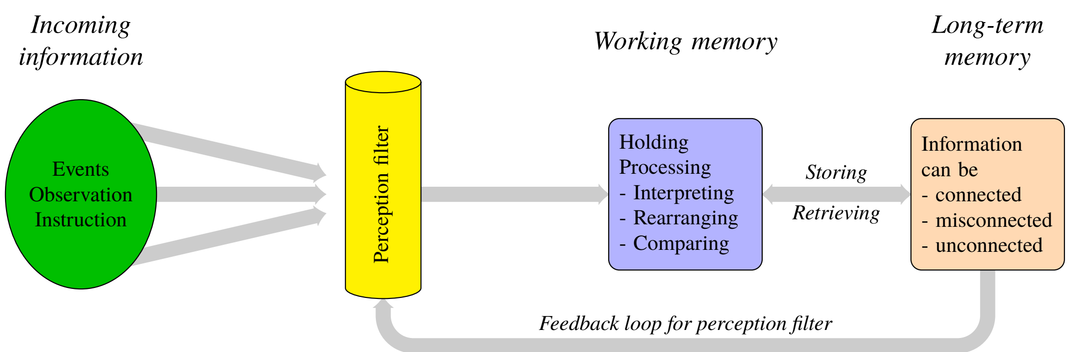


Figure 2.3: Information processing model (Johnstone, 2006)

According to the Information Processing Model, learners have a working memory space and long-term memory space. In the working memory space part, the information is processed, interpreted, rearranged, compared and stored whereas in the long-term memory part the previously acquired information is stored. The information we receive through our senses pass through perception filters to remove any unnecessary information. The information, which is recognisable and necessary, is allowed to pass through the filters and enter the working memory space as shown in Figure 2.3. The filtered information is stored temporarily in the working memory space and from there it is either lost or passed to the long-term memory space where "sense making" and connections occur with the existing knowledge schemata.

According to Bransford et al. (1999) the prior knowledge that students bring with them to the classroom can help, obstruct, or may have no impact on their learning. Any unattached knowledge cannot be stored in the long-term memory and is lost because it is not integrated into the mental system. However, sometimes learners can attach the information to unsuitable existing knowledge, which can create alternative frameworks or alternative conceptions. In applying Johnstone's model, an educator must avoid overloading the working space memory by presenting the information in a manner which maximises the "sense making" and "connection making" process and facilitates storage and recall (Johnstone, 2006).

2.3.3 Learning environment influence on students' outcomes

There has always been a rising interest to measure and investigate the importance of the learning environment in science education. The learning environment has a strong impact on students' learning experiences and outcomes as it affects students' level of enthusiasm and effectiveness of learning (Ahmed et al., 2018). According to Wong and Fraser (1996), the exploration of relationship between students' cognitive and affective learning outcomes and their perceptions of their classroom environment has been a key area of research. Several studies have supported the existence of linkage between students' perceptions of the learning environment and their outcomes (Asghar, 1993; Fraser & Fisher, 1982; Fraser et al., 1993; Fraser et al., 1986; Schibeci & Fraser, 1987). Many instruments have been developed to measure students' perceptions of psychosocial characteristics of the learning environment of classrooms at the primary (Marinopoulos & Stavridou, 2002), secondary (Gupta et al., 2015; Qureshi et al., 2017) and tertiary education levels (Vishnumolakala, 2013). One learning environment instrument, Science Laboratory Environment Inventory (SLEI), was internationally field-tested with a sample of 5447 students in 269 different classes in six countries (the USA, Canada, England, Israel, Australia and Nigeria), and cross-validated with 1,594 Australian senior high school students in 92 classes (Fraser et al., 1993).

An Australian study conducted by Fisher et al. (1997) in senior secondary biology classes also supported the use of SLEI to measure students' attitude scores. Over 400 students in 28 biology classes were involved in this study which provided some valuable information about the effect of the learning environment on student outcomes and how educators can use the information to improve their teaching practices. Wong and Fraser (1996) used Chemistry Laboratory Environment Inventory (CLEI) a modified version of SLEI with 1592 Year 10 students in secondary school chemistry class in Singapore. This study also provided some statistically significant linkage between CLEI and the students' attitudinal outcomes. Gupta et al. (2015) administered SLEI to 460 higher secondary school students in India to assess their perceptions of the science laboratory environment. The data was analysed using Analysis of Variance (ANOVA) and provides evidence for reliability and validity of the instrument.

To assess students' perceptions of the actual classroom environment and the preferred classroom environment especially for tertiary level education, College and University Classroom Environment Inventory (CUCEI) was developed (Fraser et al., 1986) and was validated by a group of science educators in Australia (Treagust & Fraser, 1986). Nair and Fisher (2001) conducted a study involving 504 students and 24 instructors; 205 students were from Canadian institutions and the remaining 299 from Australian institutions. Statistical analysis examined the internal consistency of CUCEI and it was therefore considered a suitable instrument for reporting students' perceptions about the learning environment.

A study was conducted by Booth (1992) to appraise a change from the traditional teacher-centred method to student–teacher interaction in one learning environment. In this study, 30 final year dental students at the University of Western Australia, were administered CUCEI to measure students' and teachers' perceptions of the learning environment. The key findings of this study supported the concept that an enhancement in the learning environment had a positive effect on student-teacher interaction.

The findings from aforementioned studies shaped and framed the research question for the present study, to explore the impact of the students' perceptions of the learning environment on their learning experiences and outcomes.

2.3.4 Attitudes influence on students' outcomes

Attitude according to Kind et al. (2007) refers to the way an individual feels about an object based on their understanding of the object. Many social psychologists believe that attitudes have three different components (Eagly & Chaiken, 1993; Rajecki, 1990): affective, behavioural and cognitive as shown in Figure 2.4. The affective component is the emotional (liking/disliking), behaviour component indicates individuals' intentions and cognitive component represents individuals' beliefs' towards an attitude object (Brown et al., 2014; Jain, 2014).

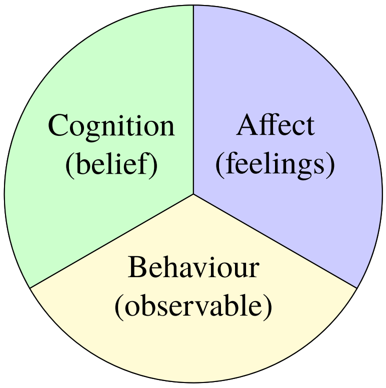


Figure 2.4: Tripartite model of attitude (Jain, 2014)

Many studies conducted at secondary (Guzmán et al., 2005) and tertiary levels (Juter, 2005; Reynolds & Weigand, 2010) have demonstrated a positive and significant relationship between students' attitudes and educational outcomes and particularly in relation to chemistry (Brandriet et al., 2011; Kahveci, 2015; Xu et al., 2013). The literature has indicated that students' interest in science declines from middle school to high school (George, 2006; Lyons, 2006) and in the long run negative attitudes can harm students' performance (Yaratan & Kasapoğlu, 2012). An effective teaching environment plays a major role in fostering a positive attitude towards science (Papanastasiou & Zembylas, 2002). Responsibility now lies on educators as they can play an important part in developing students' positive attitudes towards science by implementing student-centred teaching pedagogies (Ebenezer & Zoller, 1993).

A wide variety of tools are available to gather data on students' attitudes. Quantitative tools such as questionnaires allow researchers to collect data from a large sample in a short amount of time. They are easy to administer and the data collected is easy to analyse (Williamson et al., 2002). Akinbobola (2009) conducted a quasi-experimental study involving 140 Nigerian senior secondary school students to find out their attitude towards the use of cooperative, competitive and individualistic learning strategies. Students' Attitude Towards Physics Questionnaire (SATPQ) questionnaire was used to collect data and results showed that cooperative learning strategy was most effective in facilitating students' attitudes towards physics. To measure students' attitudes towards chemistry, researchers have used many valid and reliable surveys and questionnaires such as Chemistry Attitudes and Experiences Questionnaire (CAEQ) (Dalgety et al., 2003), Attitudes to the Subject of Chemistry Inventory (ASCI) (Bauer, 2008) and a revised version of Attitude towards the Subject of Chemistry Inventory, version 2 (ASCIv2) (Xu & Lewis, 2011).

Vishnumolakala et al. (2017) carried out a mixed-methods study to investigate how POGIL impacts the attitudes, self-efficacy and experiences of 559 first year undergraduate chemistry students. To measure the attitude towards the study of chemistry, ASCIv2 and CAEQ were modified and used. The post-POGIL perceptions of the students' attitudes and self-efficacy and experiences were proved to be statistically significantly higher and the acceptable Cronbach's alpha values further supported the reliability of the instruments in this study.

The above studies laid the foundation to develop the research question for the present study, to explore the impact of the students' attitudes on their educational outcomes.

2.4 Pedagogies supported by social constructivism

In traditional teacher-centred methods, the teacher is the source of knowledge and the vast majority of class time is spent with the teacher talking and students watching and listening (Gibson, 2001). Non-traditional student-centred teaching strategies such as active learning, guided-inquiry learning and cooperative learning which forms the basis of POGIL, can be used to enrich the excellence of teaching and learning in classrooms. The following section discusses the literature review supporting the positive impact of these teaching strategies which led the researcher to trial POGIL in her chemistry classes.

2.4.1 Cooperative learning

Instructional models based on social constructivism stress the need for cooperative learning amongst the learners which is one of the active learning methods used by many educators in their classes to help their students learn and understand. In cooperative learning students are placed in small teams and each member of the team is assigned a specific role and every one participates to achieve the final goal (Adams, 2000). A successful cooperative team must have a positive interaction and accountability both as an individual and as well as a group. A positive interaction involves communication between students that is beneficial to them. If students are individually accountable or responsible for their learning, they can contribute positively to their group. A team environment promotes skills such as problem solving, critical and analytical thinking, teamwork, communication (Ghaith, 2002; Johnson et al., 2006; Slavin, 1991) and improves academic performance (Ledbetter, 2002; Pintrich, 2003; Stevens & Slavin, 1995) as well as reduces the students' chemistry anxiety level (Oludipe & Awokoya, 2010). In addition to an increase in academic achievement, cooperative learning also increases student's acceptance of each other's differences, an important life skill (Kreider, 1992; Ziegler, 1981) which students need beyond the classrooms and lecture rooms.

Johnson and Johnson (1986) published a meta-analysis of more than 600 research studies covering all age groups and disciplines and found that students taught using cooperative learning methods learned more compared to students working individually. They suggested that educators should make small heterogeneous groups of not more than four students by providing them with a clear goal as well as expected behaviours such as participating actively, supporting and encouraging others. According to Duchesne and McMaugh (2019), when more competent students work together with less competent students they can help move forward the later students' zone of proximal development through scaffolding by modelling of language or thinking strategies.

2.4.2 Active learning

Active learning is based on the theory of constructivism, which emerged throughout the late 20th and early 21st centuries. An educational reformer and philosopher Dewey (1997) believed that schools are social institutions where students develop knowledge and social skills necessary for a democratic society. He depicted students as active participants who gain knowledge by engaging in group discussions rather than being just passive recipients. Lewin (1947) introduced the term "group dynamics" stating that a change in the state of mind of any individual changes the state of mind of other members of the group. Active learners do not just merely believe what they read or what they are told; rather they try to make connections and look for patterns. When students learn from each other and share knowledge working in groups, they receive immediate feedback and take responsibility of their own learning thus fostering deeper learning and retaining knowledge for a longer time compared to other traditional instructional formats.

According to Freeman et al. (2014), students are actively engaged during activities and class discussions, as opposed to traditional method where they listen passively to their teacher. Active learning which emphasizes higher-order thinking and often involves group work comprises of two core features; the students' activities and the engagement processes. Engagement of the student in the learning process is seen as a key to long-term retention of knowledge (Farrell et al., 1999; Moog et al., 2009). Students feel more satisfied with their courses if they feel connected, engaged and included in their learning (Davis, 1993) and this is when they learn more effectively (Adams, 2000; Ledbetter, 2002).

Recently a study was conducted to test the effectiveness of constructivist versus exposition-centered course designs by meta-analysing 225 studies in undergraduate science, technology, engineering, and mathematics (STEM) courses (Freeman et al., 2014). It was found that in active learning units, average examination scores were enhanced by about 6% and those students in classes with traditional lecturing were 1.5 times more likely to fail than students in classes with active learning.

Sesen and Tarhan (2011) conducted a study involving 45 students to investigate the effectiveness of active learning implementation on high-school students' understanding of acids and bases. Students' achievement in the post-test were statistically significant for the experimental group. The study revealed that active learning not only improves students' learning achievement but also reduces alternative conceptions.

2.4.3 Inquiry learning

Inquiry learning is a type of active learning. It is defined as a systematic method of teaching in which students follow methods and practices similar to those of professional scientists in order to construct knowledge (Keselman, 2003). In the inquiry learning process, students actively investigate by posing questions and seeking answers to their problems through the process of observation and critical thinking.

The term inquiry has figured prominently in science education. From a science perspective, inquiry-based teaching engages students in processes such as observing, comparing, contrasting and hypothesising (Cuevas et al., 2005). As claimed by Minner et al. (2010), in science education, inquiry refers to three distinct categories of activities: what scientists do (e.g., conducting a scientific investigation), how students learn (e.g., actively inquiring through thinking and solving a problem) and a pedagogical approach employed by teachers (e.g., designing or using curricula that allow for extended investigations). In inquiry-based learning there are three mediums, namely inquiry, discovery and experiences (Shamsudin et al., 2013). As stated by Tamir (1985) inquiry learning involves students posing questions, formulating hypotheses, designing and conducting experiments to verify them, analysing data, providing explanations using their evidence and communicating the scientific information.

Historically, Schwab and Brandwein (1962) introduced two types of inquiry: stable inquiry where teacher provides the questions and materials to the students and

Table 2.1: Types of inquiry learning (Bell et al., 2005)

Confirmation Inquiry	Structured Inquiry	Guided Inquiry	Open Inquiry
Students confirm already existed information provided by the teacher.	Students engage in questions provided by a teacher or their textbooks.	Students develop the procedure to explore problems provided by a teacher.	Students form their own questions about a topic selected by their teacher.
Students follow through an activity in which results are known in advance.	Students follow teacher instructions to conduct an experiment. However, they are responsible for the interpretation of the results.	Students design, conduct their investigations and interpret the results, with teacher acting as a facilitator.	Students design, conduct their own investigations and interpret the results.

Closed ended ⟷ Open ended

High — Teacher's help — Low

fluid inquiry where students generate their own questions and conduct experiments. Later, Herron (1971) proposed a scaled model of inquiry which was adapted by Bell et al. (2005). As presented in Table 2.1, according to this model there are four types of inquiry learning methods: confirmation inquiry, structured inquiry, guided inquiry and open inquiry method. The confirmation and structured inquiry methods are more closed-ended, teacher-centred methods which involves excessive teacher input whereas the guided inquiry and open inquiry methods are open-ended and student-centred methods with minimal input from the teacher.

Many researchers agree that both the guided and open inquiry method promote the development of inquiry and critical thinking skills. Some educators prefer the open inquiry method (Zion & Sadeh, 2007) arguing that it promotes the development of higher level inquiry skills and sharpens the mental processes (Berg et al., 2003; Yen & Huang, 2001). There are research studies which also support the view that guided inquiry learning promotes development of high level of inquiry skills among the students (Flick & Lederman, 2004) and help students understand and learn science content (Quintana et al., 2005; Reiser et al., 2001). Science educators can help students learn through inquiry by targeting activities towards concrete observable concepts (Colburn, 2000). They must choose activities suited to the students' skills and knowledge by using familiar materials and situations. The questions should not be too easy so that they stay in their comfort zone and may fail to develop critical thinking, but also should not be too difficult otherwise students may give up without trying.

Chatterjee et al. (2009) conducted a study to analyse general chemistry students' attitudes and perceptions toward guided inquiry and open inquiry laboratories. The survey results found that students' have positive attitudes towards guided inquiry as their conceptual understanding increases. In a longitudinal study conducted at Hampshire College from 1992 to 1994 (Gibson & Chase, 2002), inquiry-based learning was found to have long term positive effects on students' attitudes towards science. However, the opponents of open inquiry method argue that it can lead to a waste of time and frustration due to achieving undesirable results (Gallagher & Tobin, 1987; Trautmann et al., 2004).

There are numerous student-centred pedagogies such as Process-oriented guided inquiry learning (POGIL), peer-led team learning (PLTL) and Problem Based Learning (PBL) which have been recognised by many educators (Eberlein et al., 2008; Raker et al., 2021). The theoretical basis for POGIL is the learning cycle whereas PBL is more about an individuals' "need to know" learning and PLTL is Peer-led team learning (Eberlein et al., 2008).

Building on this, the researcher decided to use POGIL in her chemistry classes based on the premises that students learn better when they construct knowledge by actively engaging in small group discussions.

2.5 Process Oriented Guided Inquiry Learning

POGIL is an emerging student-centred methodology which was developed in the mid 1990s and can be defined as a hybrid of three learning theories; active learning, inquiry-based learning and constructivism (Moog et al., 2009; Raker et al., 2021). POGIL is a teaching method that enables students to learn through group interaction and problem solving. As mentioned by Hale and Mullen (2009), the students must construct their own knowledge for an effective learning experience and they must use real world experiences to understand the concept. Further research by Bransford et al. (1999) supports that learners learn by constructing their own knowledge based on their preconceptions following a cycle of learning. They must interact with others to connect and visualise the concepts.

POGIL not only aims to develop students understanding of the concepts by carefully guided exploration process, but also to develop and improve many important non-content learning skills such as teamwork, oral and written communication, management, assessment, problem solving, critical thinking and metacognition (Hanson, 2013). According to Moog et al. (2009), " POGIL is both a philosophy and a strategy for teaching and learning. It is a philosophy because it encompasses specific ideas about the nature of the learning process and the expected outcomes. It is a strategy because it provides a specific methodology and structure that are consistent with the way people learn and that lead to the desired outcomes".

The principle learning object in the classroom implementation of POGIL is a carefully constructed inquiry-based activity comprised of guided questioning of a process or processes. The guided questions are modelled around a learning cycle paradigm. The students work through the activity within highly structured groups that is facilitated, rather than taught, by the instructor. According to Spencer and Moog (2008), in a POGIL paradigm, the teacher/instructor serves as a facilitator, not as a source of information and learners work in self-managed teams on POGIL activities to explore concepts and construct understanding. The researcher decided to implement POGIL in her chemistry classes as it not only increases students' cognitive knowledge, but it also allows for the development of essential skills such as teamwork, communication, problem solving and critical thinking.

2.5.1 Learning cycle model

A cognitive model for learning explains the entire process associated with the attainment of novel knowledge. Many models have been developed based on studies in various disciplines. The main emphasis of this study is on POGIL activities which are designed and based on the Karplus learning cycle model. Incorporating the learning cycle model, researcher has developed Year 8 and Year 11 chemistry POGIL activities which are discussed in Chapter 4. A complete copy of the worksheets is presented in Appendix E and F.

The learning cycle is a model of instruction grounded on scientific inquiry and explains the process of how an individual learns. The concept of learning cycle was developed by Karplus and Butts (1977) while working on an Elementary School Science Project as part of Science Curriculum Improvement Study in late 1970s. It has been used for teaching elementary school science. The activities in POGIL are modelled around a Karplus learning cycle approach (Abraham, 2005; Kolb, 2015; Lawson et al., 1989; Spencer, 1999) which consist of three phases: exploration, concept introduction, and application as shown in Figure 2.5. In the Karplus learning cycle model, exploration allows students to become interested in the subject and raise questions. This is followed by an introduction of new concepts and terms, mainly by the instructor, but with the help of students. Finally, learners apply their new ideas and understanding to new contexts.

Exploration: In the first phase, students work on models, data, or examples in small groups with nominal teacher direction. The information can also be provided in the form of slides, audio or video depending upon the activity. Students formulate and record ideas and hypothesise, which are tested later.

Concept development: During the concept invention phase, students develop an understanding of the concept and identify its importance and significance by relating it directly to the patterns identified during exploration. The teacher may give extra information to help students to develop more concepts and scientific vocab-

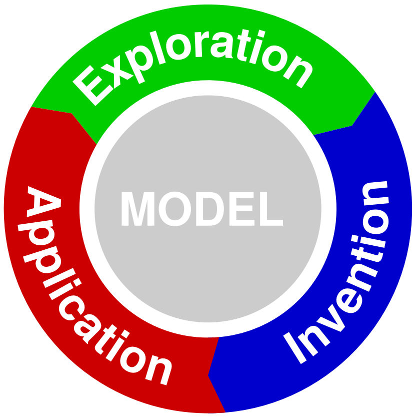


Figure 2.5: Karplus learning cycle approach (Karplus & Butts, 1977)

ulary. The terms are introduced at the end once the concept has been developed.

Application: This is the last phase of the Karplus learning cycle, which involves applying the conceptual knowledge gained to new learning situations. At this stage, students work independently with minimum teacher's assistance. Sometimes if the concept needs to be refined it is returned back to the exploration phase where further exploration and refining of knowledge takes place.

The researcher decided to adopt the Karplus learning cycle model in her chemistry classes as it is interactive and enables teachers and students to make learning sustainable by providing students with future-focussed skills and experiences.

2.5.2 Effectiveness of POGIL

Many studies have tested and supported the effectiveness of POGIL at a range of institutions. Farrell et al. (1999) conducted the first study at Franklin and Marshall College when they implemented POGIL with students studying a general chemistry course in the fall of 1994–1997. They compared the results to students who studied general chemistry in the fall of 1990–1994 by experiencing traditional methods. Their findings are presented in Figure 2.6.

The percentage of students earning a D, W and F grade dropped from 21.9% to 9.6% whereas the A grade increased from 19.3 to 24.2%, B increased from 33.1% to

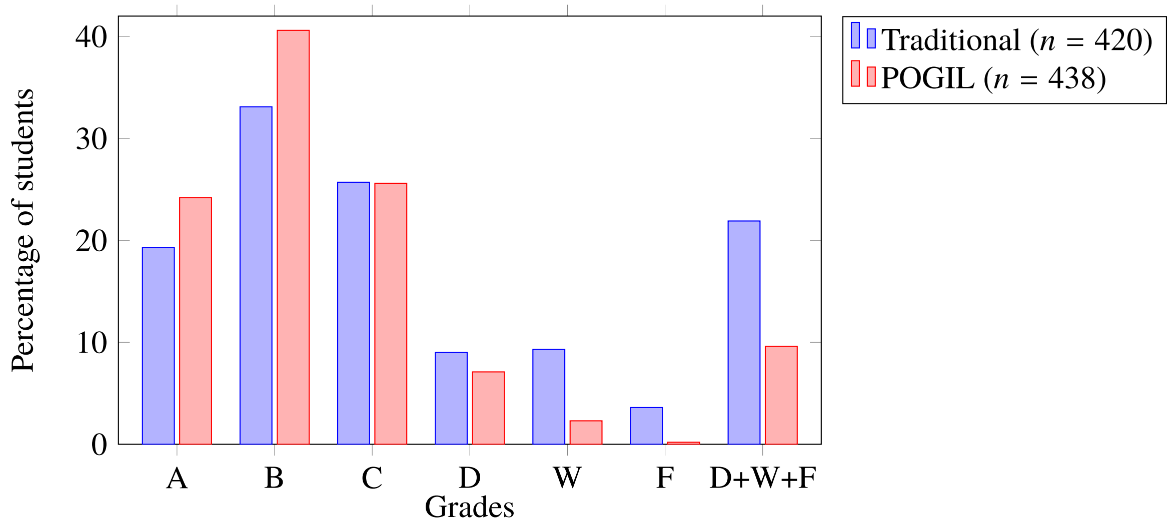


Figure 2.6: Percentage of students earning different grade, adapted from Farrell et al. (1999)

40.6% and C grade appeared the same (Farrell et al., 1999). Also, 12.3% students who were achieving D, W and F grades when taught using a traditional teacher-centred method, improved to C grade, thus causing a subsequent progression towards B or A grade thereby reducing the number of students achieving below C grade.

Lewis and Lewis (2005) conducted a study at the University of South Florida in a general chemistry class using PLTL, a student-centred pedagogy in which students work in groups of ten which is led by a peer leader who has successfully accomplished the undergraduate chemistry course. They studied the effect of replacing one of three general chemistry lectures each week with a PLTL session using POGIL based worksheets. They termed this approach Peer-Led Guided Inquiry (PLGI). They discovered that the students who attended the group learning sessions outperformed the control group in the common examinations.

An action research study conducted by Murphy et al. (2010) examined the implementation of POGIL in a preparatory college chemistry course consisting of approximately 180 students in three lecture sections per semester for two years at a large suburban university. The initial experimental design consisting of a control group (no POGIL treatment), a partial group (partial POGIL treatment) and a full group (full POGIL treatment) failed to generate any statistically significant results. For the second implementation, the POGIL activities were altered by eliminating many of the reading components and integrating mini lectures into the activities which led to a positive effect on student's performance.

Şen et al. (2016) conducted a study at a public school in Turkey. Participants were 115 11th grade students and their understanding of electrochemistry was tested. The experimental group ($n = 65$) and control group ($n = 59$) were administered the Electrochemistry Concept Test (ECT) consisting of 19 questions to assess the students conceptual understanding and alternative conceptions in electrochemistry concepts. The ECT was administered to both groups as a pre-test and post-test. The results were compared using a t-test, which found that the experimental group had a significant gain of 6.82 compared to the control group mean of 4.53, thus supporting POGIL's positive impact on conceptual understanding. He also found that students in the experimental group had fewer alternative conceptions as compared to the control group.

Vishnumolakala et al. (2017) conducted a mixed-methods study to analyse experiences of 559 first-year undergraduate chemistry students from two cohorts in modified POGIL classes. The ASCIv2 and CAEQ were adopted and administered to students in a pre and post setting. The POGIL intervention provided positive affective perceptions of attitudes, self-efficacy and experiences of students who have limited prior chemistry knowledge.

Finally, it is worth mentioning the positive impacts of POGIL in other fields of science as well. Brown (2010a) implemented POGIL for two years in an introductory anatomy and physiology course at a small private college. The course had a diverse student population with some students having no previous college level science experience to some having junior and senior biology, biochemistry and forensic science majors. POGIL implemented in the second half of the semester significantly enhanced students' achievements in end of unit assessments. The results showed that the overall course score increased from a mean of 76% to 89% after the implementation of POGIL. Performance on the same multiple-choice final exam also increased from a mean of 68% to 88%. Furthermore, after the introduction of POGIL, the rate of students scoring a D or F grade in the course was reduced by half in the first two semesters and was 0% in the third semester. Students' perceptions about the importance of group work and peer support in helping them to understand the concepts also increased.

Subsequently, many researchers have implemented POGIL successfully in organic chemistry (Chase et al., 2013; De Gale & Boisselle, 2015; Hein, 2012; Shatila, 2007; Vishnumolakala, 2013), physical chemistry (Spencer & Moog, 2008), biochemistry (Geiger, 2010; Minderhout & Loertscher, 2007), medicinal chemistry (Brown, 2010b) and high school chemistry (Barthlow, 2011; Barthlow & Watson, 2014). Researchers have noted that POGIL has a positive impact not only in chemistry but also in other areas of science such as pharmaceutical science (Soltis et al., 2015) and computer science (Hu et al., 2016). The success stories of POGIL go beyond science as it has been found to impact positively in psychology (Vanags et al., 2013), marketing (Hale & Mullen, 2009), nursing (Coomarasamy & Hashim, 2016), anatomy and physiology (Brown, 2010a), mathematics (Abdul-Kahar et al., 2016; Bénéteau et al., 2017) engineering and management (Kode & Cherukuri, 2014).

The above mentioned studies clearly highlights the success of POGIL in different classroom settings, which led the researcher to trial POGIL in her chemistry classes.

2.5.3 Characteristics of POGIL activities

The main objectives of POGIL activities as outlined on the POGIL website (POGIL, 2019) are as follows:

- POGIL materials are designed for use with self-managed teams under the facilitation of an instructor.
- POGIL materials support students to construct their understanding of concepts.
- POGIL materials facilitate the development of higher-level thinking skills and the ability to learn and apply knowledge in new environments

POGIL activities intend to develop conceptual knowledge and processing skills while keeping the learner engaged in the process. There are two types of POGIL activities. Any POGIL activity generally falls in one of the two categories or sometimes is presented as an amalgamation of both activities.

Learning cycle activities: These activities are intended to develop new concepts and they guide the learner to develop conceptual knowledge through Karplus learning cycle of exploration, concept invention and term introduction (Minderhout & Loertscher, 2007).

Application activities: These activities are constructed on a concept that has been already presented before in a separate activity or is presented in the same activity. It helps learners to deepen their understanding of the concept through application of relevant processes.

POGIL activities are structured on Karplus learning cycle of exploration, concept formation and application, a concept that has been previously presented whether in a separate activity or the same activity (Hanson, 2013). The POGIL learning cycle integrates Bloom's taxonomy's first three levels — knowledge, comprehension and application (Soltis et al., 2015). While teaching students the core concepts, it also develops processing skills such as critical thinking, problem solving, and communication, all of which are an indispensable part of science education. Teachers can target one or two process skills for learner development. While engaging the students actively in the learning process, POGIL requires them to work collectively towards understanding the core concept (Murphy et al., 2010).

A typical POGIL activity starts with some information provided to the learners in a model (Brown, 2010b) which may be in the form of diagrams, graphs, equations, demonstrations, data or a small prose. This is followed by some carefully guided critical thinking questions. In order to develop confidence and knowledge, activities start with simple questions built on student's prior knowledge. This introduction is followed by complex questions leading to the development of the concept (Spencer & Moog, 2008). The teaching approach enables students to understand the concept before inventing the terminology. Teachers should not provide answers to problems faced by the students but rather following the learning cycle model, and guide and encourage them to think about the problems and find out the solutions. The last section of the POGIL activity has some questions and activities where the learner applies the acquired knowledge and understanding to new situations.

2.5.4 POGIL implementation and different roles

The implementation of the POGIL method plays an important role in this research study. When students work in small groups, they tend to understand the concept better and retain it longer as compared to when taught using other instructional pedagogies. In a POGIL classroom, students work in heterogeneous teams of three or four students (Hanson, 2013; Johnson et al., 2006) supporting and helping each other. In a small group, learners can focus better as there tends to be fewer distractions.

A group should ideally be a mix of high performing and low performing students. There is a mutual relationship as high performers benefit by explaining concepts and low performers benefit by group participation (Shatila, 2007). When designing groups, teachers must make sure that all group members work collaboratively to achieve a common goal. Teachers must not put loud students and quiet students in the same group. The loud students may dominate the group, giving no chance to the quiet students in the group discussions. If there are some students who are reluctant to speak and contribute despite having some good ideas then the academic performance of the group suffers (Cohen, 1990). These quiet members of the group are not committed to the aim of the activity.

The teacher should spend some time at the beginning of the activity explaining the POGIL methodology and the reasons for it. Students can also use self-assessment sheets where they analyse their own group. The motivation of participants has been noted to be one of the most serious problems in group work (Kerr & Bruun, 1983).

To generate equal participation among the group members, each student is assigned a role which can differ according to the size of the classroom (Brown, 2010b; Farrell et al., 1999; Hanson, 2013). The typical POGIL roles are:

1. Manager is the head of the group who works with other members and ensures that all are working together to accomplish the assigned tasks on time, including that all members of the group participate in activities and understand the concepts.

2. Presenter or the spokesperson presents oral reports to the class. These reports should be as concise as possible; the instructor will normally set a time limit.

3. Recorder keeps a record of the group's official answers as well as the group's observations and insights etc. in their workbook and prepares the final report in consultation with the others.

4. Reflector or strategy analyst observes and comments on group dynamics and behaviour with respect to the learning process.

5. Technician is responsible for performing all the technical work to assist the group, including performing calculations, locating content in the textbook and using computers or any other equipment.

In addition to this, additional roles may include:

6. Encourager who motivates the group.

7. Librarian is the person who can use a textbook if their group cannot remember the information needed to answer the questions.

Educators have the flexibility to adapt this model either using POGIL for every lesson (Farrell et al., 1999) or using the model only for some sessions (Cole et al., 2012; Lewis & Lewis, 2005; Murphy et al., 2010). In the present study, the researcher embraced the roles of manager, presenter, recorder and reflector for the students.

2.5.5 The role of a teacher in a POGIL classroom

In a POGIL classroom, the teacher has very important, different roles to play. The teacher is not the source of the information rather he/she serves as a facilitator who guides the students to achieve the desired learning outcome by providing the learning environment. The teacher has four very important roles to play: leader, assessor, facilitator and evaluator (Hanson, 2013).

As a leader of the learning process, the teacher constructs the learning atmosphere and identifies the learning objectives and the process skills needed to be covered. The teacher also establishes the structure required for the team, classroom and the time management.

As an assessor, the teacher moves around during the activity to evaluate each teams' individual and group academic performance and structural problems. The teacher identifies the difficulties and alternative conceptions experienced by the students.

The third important role for a teacher to play is a facilitator. A successful POGIL facilitator must have skills of listening, rephrasing questions and asking critical thinking questions (Minderhout & Loertscher, 2007). The teacher moves around the class and if a team is struggling to understand the concept, the teacher interacts with them by posing questions in ways that encourage rather than endorse deeper thought. The teacher should not provide answers to the questions but instead help the students to reach the answers themselves. The teacher should keep the interference to a minimal level and if the students are working fine, no intervention is required. The teacher joins a group as an observer for a brief interval of time and listens to the interaction the students have to make sure that they all are actively engaged in the learning process. The teacher should resist the temptation to correct students' mistakes and rather let them find out their mistakes themselves.

Educators must create a facilitation plan to help them guide students to develop conceptual understanding as well as process skills while working in small self-managed teams. Minderhout and Loertscher (2007) sketched a facilitation plan as shown in Figure 2.7 to help teachers deliver successful learning before, during and after the activity.

Lastly, as an evaluator, the teacher sums up the activity by asking each team member to report answers, summarise the main points, their strategies and results. The teacher collects data and information from each team and provides them the feedback regarding their performance and achievement. In the present study, the researcher adopted all

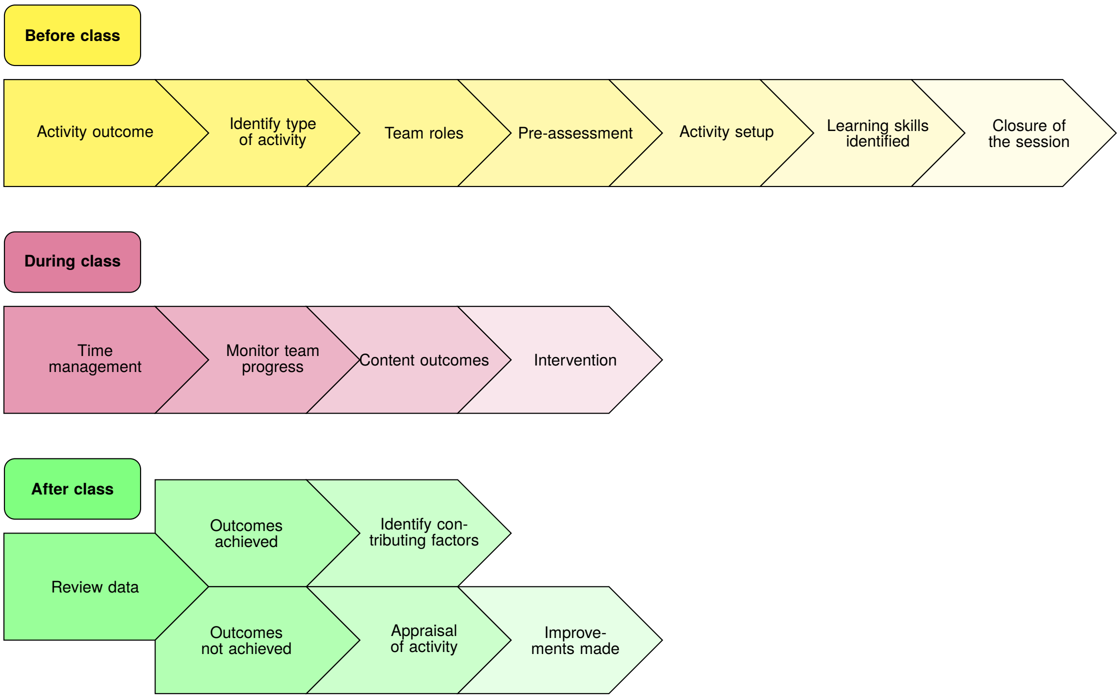


Figure 2.7: POGIL facilitation plan (Minderhout & Loertscher, 2007)

four roles of leader, assessor, facilitator and evaluator, which are all essential parts of a POGIL classroom.

2.5.6 Process skills

The emergence of globalisation and technology has changed the traditional employment criteria such that traditional skills alone are not sufficient to gain employment in today's world (Pompa, 2015; Timm, 2005). Employability refers to skills and capabilities that make an individual more likely to gain employment. These skills are dynamic and are shaped by the economic and market demands (Jollands et al., 2016). The 2019 Graduate Outlook Survey report published by Graduate Careers Australia (GCA) found that the main skills pursued by employers were interpersonal and communication, reasoning and problem solving, leadership, technical skills and emotional intelligence including self-regulation skills (Challice et al., 2019) .

According to Glenn (2003) and Kivunja (2014), employers look for employees who can perform basic tasks like processing and problem solving and also can interact effectively and professionally with others. Bharathi et al. (2016) and Hartman and LeMay (2004) emphasised the importance of communication skills for students with an aim to enhance their employability prospects. These skills are a new way to portray a set of abilities or talents that a person can bring to the workplace (James & James, 2004).

Science researchers have supported the notion that both science content and science process skills are an important part of the learning process (Shatila, 2007; Toyo et al., 2019). Students should be taught higher order cognitive skills by engaging them in the excitement of science. Hanson (2013) outlined seven important process skills required for science education. They are: information processing, critical and analytical thinking, problem solving, communication, teamwork, management, and assessment. According to a report published by Kussmaul (2016), courses such as computer science require students to have both content knowledge and process skills. To achieve this, the teaching faculty used Team Project Based Learning (TPBL) and POGIL approaches.

Several studies in biochemistry and pharmaceutical science have shown that students' process skills are enhanced in POGIL classes. Bailey et al. (2012) evaluates the implementation of POGIL in large biochemistry classes and found positive impacts of POGIL in teaching as well as learning. Students' process skills such as communication, higher order thinking, teamwork and time management were enhanced. Correct pronunciation of vocabulary is very important in biochemistry and it was reported that students from POGIL classes were 57% less likely to mispronounce the words. Murray (2014) studied the impact of using POGIL activities to teach students to read and interpret the primary literature in a major biochemistry sequence. Data supported that students were able to learn content just by using the primary literature and also their comfort and confidence level increased when approaching the literature. POGIL helped to improve important science skills such as the ability to read, interpret and evaluate articles. Soltis et al. (2015) documented the effectiveness of POGIL strategy on enhancing students' problem solving and critical thinking skills in a pharmaceutical science course. The questions in the examinations were placed into lower-level requiring knowledge and/or comprehension and higher-level requiring application and/or analysis based on Bloom's Taxonomy. There was an insignificant difference in the students' performance (92% to 91.4%) in lower level questions however student's performance in higher level questions significantly increased from 75.8% to 82.8%. Students' problem solving and critical thinking skills also increased with POGIL. The success of POGIL in the above mentioned studies encouraged the researcher to implement POGIL in her chemistry classes.

2.5.7 POGIL in Australia

Following a report submitted by Bedgood et al. (2010), the members of Active Learning in University Science (ALIUS) have been effectively implementing POGIL across many disciplines. POGIL practitioners in the USA, Australia and New Zealand collaborate periodically to conduct workshops to train and provide supervised support to implement the student-centred teaching method. The POGIL workshops were revised and redesigned to meet the Australian classroom culture and implemented in first-year undergraduate courses.

During the initial implementation of POGIL in 2009 at their member institutions, the instructors used POGIL worksheets as homework activities which was followed by discussions by students during tutorial sessions. Some students enjoyed doing the POGIL worksheets whereas other students did not like them. Based on students' feedback, instructors embedded group work questions into the lecture which was well received by the students. Students enjoyed switching between lecture style and the active group learning and supported this blended approach. The results indicated no change in the average and median grades. However, the proportion of high-distinctions increased and the proportion of distinctions and credit grades decreased. There was also an increase in the proportion of fail grades due to a number of factors including instructor's inexperience in using POGIL activities. In 2010, semester 1, POGIL was trialled in another first-year chemistry module. The results were compared between POGIL and traditional classes. Again, students supported the blended POGIL approach and their quiz scores revealed a significant increase in proportion of high-distinction, distinction, credit grades and a drop in fail grades.

In an Australian study conducted at Curtin University, Vishnumolakala (2013) explored the effect of POGIL on students understanding of stereochemistry and their perceptions of learning chemistry in first year undergraduate chemistry classes. He used a quasi-experimental mixed-method research design. A post-test and a delayed post-test were given to group 1 cohort (taught using POGIL pedagogy) and group 2 cohort (taught using traditional lectures). He reported a statistically significant mean difference for students taught using the POGIL method compared to students taught using traditional instructional method, thus supporting POGIL as a more effective pedagogy.

In another study, (Williamson et al., 2013) redeveloped "Foundations of Chemistry" course for 2012, undertaken by undergraduate students pursuing a wide variety of degrees that require a year of chemistry study. The students had little or no chemistry background. The POGIL style activities were used to deliver majority of the course content. The data collected in the form of student surveys and feedback was used to refine and further develop these POGIL activities. Students reported that they enjoyed POGIL activities and appreciated being asked their opinion about the future development of course material.

In Australia, POGIL has been successfully implemented at university level (Trevathan et al., 2014; Vishnumolakala, 2013) however, no one has reported using POGIL at a secondary school level. This situation presents an opportunity for the researcher who is also a teacher to implement POGIL in her Year 8 and Year 11 chemistry classes and investigate its effectiveness.

2.6 Action research

Action research is an inquiry-based process seeking to promote individuals' and organisations' development. Traditionally, Lewin (1946) is associated with the term "action research" which aims to improve skills of both the researchers and the participants. During this process, individuals or groups can improve teaching practices through a re-

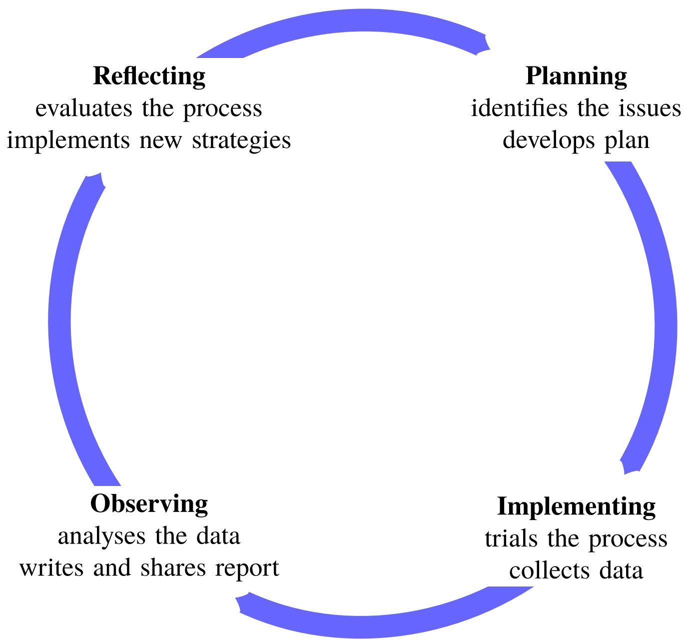


Figure 2.8: Action research cycle (Kemmis & McTaggart, 2005)

peated cycle of action planning, implementation, observing, evaluating and reflecting (Hine, 2013; Hult & Lennung, 1980; Kemmis & McTaggart, 2005; Lewin, 1946) as described in Figure 2.8.

The first phase involves planning, where an issue or the problem in the current teaching practice is identified. It is then followed by careful planning of the process to address the issues identified. The process is implemented in the classroom and data are collected by means of surveys, tests or observations. This phase is followed by reflection where the data collected is analysed and reflected upon to revise and implement the new teaching strategies. Again, the cycle of implementation, observation and evaluation is repeated. The cyclic nature of action research is evident from the fact that reflection is based on the experiences of actions. In each cycle, the results indicate whether or not the intended result was achieved, and thus the process can be further reviewed if necessary (Williamson et al., 2002).

Many researchers have supported the collaborative nature (Noffke, 1997) of this method where an assumption is made that the researchers will share their findings with others (Feldman, 1999). Action research helps educators to find ways to improve student learning as well as improving their professional skills. Hine (2013) argued that universities must include action research as a core unit in teaching degree courses as this design helps teachers to improve their teaching practices and skills.

Kitchen and Stevens (2008) conducted an action research study involving pre-service teachers. The data was collected in the form of pre-service teachers' action research proposals, reports and reflections. They found that familiarising pre-service teachers with action research can benefit them to develop professionally. In an Australian study, Krogh (2001) proposed action research as an educational model which encourages a chain reaction leading to learning occurring at multiple levels. He explored the concept of action research as "learning by doing" where learning occurs through reflection on experiences.

Segal (2009) carried out a study to investigate the claims about the benefits of action research. The sample involved 45 teachers completing their master's degree in mathematics education during the previous years. Both qualitative and quantitative data were collected by means of surveys and interviews of graduate students as well as their projects. This study also supported that action research is a useful self-empowering device that enhances teachers' professional skills and practices. Motivated by these studies, this researcher, being a teacher, adopted the action research approach to evaluate the effectiveness of POGIL in her classes which laid the foundation for the present research study.

2.7 Studies related to the topics used in this study

The particle theory of matter forms the basis of almost every topic studied in chemistry and therefore it is very important that students have a strong understanding of this theory for their future success in chemistry (Harrison & Treagust, 2002; Othman et al., 2008). Barthlow (2011) conducted a study involving 318 students enrolled at four large suburban high schools. She used a "Particulate Nature of Matter Assessment", version 2 (ParNoMA2) consisting of 20 multiple-choice questions in a pre and post-test design to investigate the effect of POGIL on reducing alternate conceptions associated with the particulate nature of matter. The data, analysed using ANOVA, indicated that students who were taught using POGIL pedagogy improved their pre-test mean statistically significantly from 11.85 to a post-test mean of 14.60 compared to the group taught using a traditional method of teaching whose scores improved only marginally from 11.49 to 11.64. Furthermore, students taught using POGIL pedagogy had fewer alternate conceptions associated with the particulate nature of matter compared to students who were taught the concept using traditional pedagogy.

Villagonzalo (2014), recorded similar outcomes using ParNoMA2 with high school students from one class ($n = 41$). Students were randomly distributed to the control (POGIL method) and experimental group (Traditional method). The data collected using ParNoMA2 was found to have little difference in the overall performance of both groups. However, the adjusted mean scores suggested POGIL enhanced students' academic performance significantly compared with the traditional method.

The Acids and Bases topic is another major component of chemistry which many students find difficult to understand (Artdej et al., 2010). Researchers have conducted numerous studies involving acid-base concepts (Hand & Treagust, 1988; Lin et al., 2004; Sesen & Tarhan, 2011). Hugerat et al. (2018) conducted a study to examine how acid-base concepts can be made more relevant for students. Two approaches to teaching are compared: the Low Relevance Approach (LRA) and the High Relevance Approach (HRA). The HRA approach emphasizes learning how chemistry materials are relevant to students' daily life. The data collected using a questionnaire revealed that teaching a topic using relevancy-oriented method not only enhances students' motivation and satisfaction, but it also improves their attitudes towards science and its learning.

Cetin-Dindar and Geban (2017) conducted a study to investigate the effect of 5E (engagement, exploration, explanation, elaboration, and evaluation) learning cycle model oriented instruction (LCMI) on year 11 students' conceptual understanding of acid-base concepts and student motivation to learn chemistry. The study involved an experimental group (taught using LCMI) and a control group (taught using traditional teacher-centred method). The data collected using multivariate analysis of covariance results revealed that the experimental group students outperformed the control group students in terms of acid-base conceptual understanding. It further, supported the fact that the learning cycle based teaching method fosters higher order thinking and influences students' motivation positively.

2.8 Curriculum framework

Curriculum is a very complex term which cannot be defined in simple words nor can its depth be measured. Many researchers and authors have defined curriculum differently in their own way. According to Pratt (1994), curriculum is a "written document that summarises goals, objectives, content and evaluation methods" whereas Darder (1991) refers to curriculum as "coursework offered or required by an educational institution for the successful completion of a degree or credentialing objective" (Darder, 1991, p. 19). As mentioned by Goodlad (1979), the curriculum evaluation framework involves five domains, namely the ideal curriculum (the original vision of it), formal curriculum (the documented version of the vision), perceived curriculum (as interpreted by the teachers), operational curriculum (in action in the classrooms), experiential curriculum (learner's actual learning experience). Van den Akker (1997) elaborated it further by adding an additional domain of attained curriculum (learners resulting outcomes).

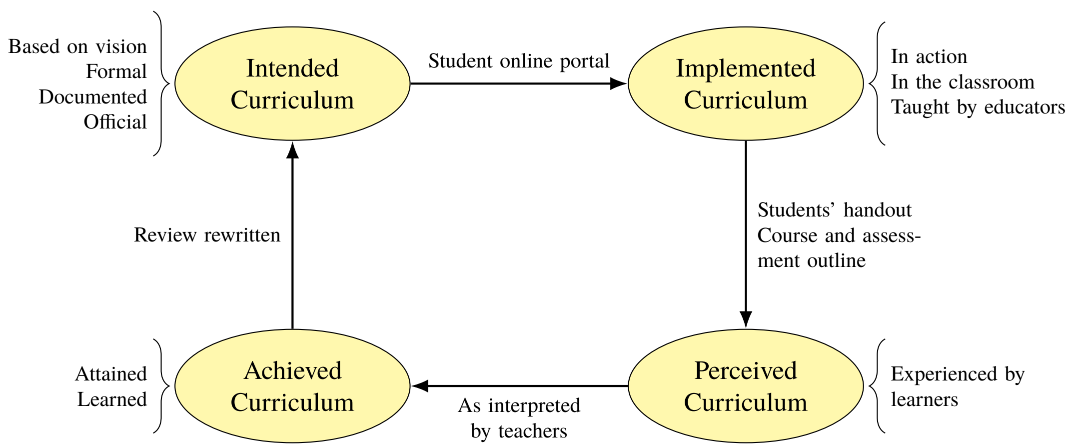


Figure 2.9: Curriculum evaluation model adapted from Keeves (1995)

According to Billett (2006) and Keeves (1995), curriculum can be grouped into three sequential stages — the intended curriculum, the implemented curriculum, and the achieved curriculum. Remmen (1999) suggested that if there are discrepancies between any of these three stages, the education becomes ineffective. Treagust (1986a) modified these three stages by adding an additional stage of perceived curriculum to assess students' perceptions. A curriculum evaluation model similar to Figure 2.9 was developed by Keeves (1995) and successfully implemented by Vishnumolakala (2013) to measure the effectiveness of POGIL in first year university chemistry classes.

The intended curriculum is also referred to as the planned or official curriculum (Bouck, 2008; Cuban, 1993; Kurz et al., 2010). In educational settings, it comprises of the syllabus, curriculum standards and frameworks which are controlled and influenced by government and other pressure groups (Billett, 2006). As described by Porter and Smithson (2001), the intended curriculum consists of guidelines that summarise the curriculum set for a particular course that teachers are expected to teach to the students. Based on the curriculum, teachers develop a syllabus which describes the detailed academic content plan for a particular subject. According to the definition presented by the Australian Curriculum, Assessment and Reporting Authority (ACARA, 2016), "the Australian Curriculum describes to teachers, parents, students and others in the wider community what is to be taught and the quality of learning expected of young people as they progress through school."

The implemented curriculum is the operational or taught curriculum (Cuban, 1993) and consists of different learning activities or experiences of the learners in order to achieve the intended curriculum outcomes. It is highly influenced by the teacher's qualifications, community or context, atmosphere of the institution and teachers' views about education (Broadway, 2009). Sometimes, due to various factors such as lack of sufficient teaching time or underestimation of teaching time, a portion of the intended curriculum is often covered briefly and in other cases it may not be taught successfully if the teacher lacks interest and qualification in that topic (Brophy, 1982; Brown, 2007).

The perceived curriculum is the curriculum experienced by the learners and many researchers have found that it may not be the same as the intended and the implemented curriculum (Haimes, 1996; Thornton, 1985). It is the curriculum that learners acquire due to their interaction with the teacher, peers or the environment. Their past experiences also play a major role in constructing the perceived curriculum.

The achieved curriculum, also known as the attained curriculum, shows students' academic achievement and attitude (Cuban, 1993; Van den Akker, 1988, 1997). It is considered as the ultimate produce of the curriculum development process and is described through test scores and other performance indicators.

The current Australian study of Year 8 and Year 11 chemistry students, is based on the above model as:

The intended curriculum: The way the Year 8 chemical science course and Year 11 chemistry course are presented based on the Australian Curriculum.

The implemented curriculum: The way in which POGIL is adopted and implemented in the Year 8 and Year 11 chemistry classes.

The perceived curriculum: Students' learning experiences.

The achieved curriculum: Students' learning outcomes.

2.9 Australian curriculum

Since the late 1980's there has been a growing demand for a national curriculum in Australia. With globalisation, technological change, complex environmental, social and economic pressures, there was a need that education must address these issues and prepare young Australians for future life once they complete their compulsory schooling (Cole, 2007). In 2008, it was unanimously agreed by the Australian Education Ministers that Australia would have a national curriculum. Keeping that in view, ACARA (ACARA, 2016) was established in 2008 with an aim to develop and implement a national curriculum so that students have access to the same content throughout Australia.

Earlier, each state and territory had an individual curriculum and the student learning and outcomes were inconsistent and could not be compared against each other. In 2008, the Ministerial Council adopted "Melbourne Declaration on Educational Goals for Young Australians", which formed the basis for curriculum development. It commits "to supporting all young Australians to become successful learners, confident and creative individuals, and active and informed citizens". Education plays an important role in shaping the lives of young Australians and helping them to grow and build up a society which values democratic equity in a culturally diverse society. ACARA works on two beliefs (ACARA, 2012):

Quality: An Australian curriculum will contribute to the provision of a world-class education in Australia by setting out the knowledge, understanding and skills needed for life and work in the 21st century and by setting high standards of achievement across the country.

Equity: An Australian curriculum will provide a clear, shared understanding of what young people should be taught and the quality of learning expected of them, regardless of their circumstances, the type of school that they attend or the location of their school.

The Australian curriculum was developed in four interconnected phases: curriculum shaping, curriculum writing, implementation, and curriculum evaluation and review. This curriculum has a three-dimensional design which focuses on:

Discipline-based learning areas: which cover curriculum for eight major learning areas.

General capabilities: which define knowledge, skills, behaviour and dispositions as important 21st century skills and are amalgamated across the curriculum so that young Australians become well-prepared for the future.

Cross-curriculum priorities: the curriculum provides students with the tools and language to better understand and engage with their world at different levels.

The Australian curriculum is dynamic and ACARA works with states, territories and the Australian Government to improve and evolve it continually. As stated by Cole (2007), within the Australian curriculum the purpose of education is to make the Australian economy more competent and productive by teaching work-related skills and competencies to our students. Further, a particular emphasis on the importance of the link between pedagogy and curriculum has been made by ACARA, stating: "Important for the design of a world-class curriculum is the recognition of the dynamic alignment that exists between curriculum, pedagogy and assessment". Both Australian Curriculum and POGIL have common goals and the importance of using POGIL over traditional pedagogy is not hidden anymore.

2.10 Summary

Teaching and learning is a complex process and many aspects can influence students' learning because the outcomes of this process differ between individuals. It is therefore important to understand how students learn, and teaching improvements must cater for students needs across a range of individual differences. The literature review associated with these issues has been discussed in this chapter. This chapter presented a theoretical framework of this study, which is based on constructivists' view and has incorporated active learning, inquiry learning, cooperative learning, information processing and cognitive model for learning. The literature emphasised POGIL's various features including its requirement, characteristics, implementation and effectiveness. The key findings of this review are:

- Several studies testified that many students regard chemistry as a difficult course.
- Social constructivism model based on cooperative learning forms the basis for science instructional pedagogy.
- Active learning, inquiry learning and cooperative learning are pedagogies supported by social constructivism.

- Many researchers recognised and supported inquiry-based learning in teaching science concepts as well as for the development of other skills such as process skills and critical thinking.

- POGIL's effectiveness can be measured by comparing pre and post-test scores and final examination scores.

- POGIL can be modified according to the classroom's learning environment.

- Students' perceptions of the learning environments created by POGIL can be measured by using instruments such as SLEI, ASCIv2 and CUCEI.

- Action research is an inquiry-based process and individuals can use it to improve their teaching practices.

- Both the Australian curriculum and POGIL have common values and goals (eg. communication, problem solving and critical thinking skills).

- A curriculum evaluation model can be grouped into the intended curriculum, the implemented curriculum, the achieved curriculum and the perceived curriculum.

Chapter 3

Methodology

3.1 Introduction

Methodology within the research process outlines a comprehensive framework for the methods used to collect data, and the underlying principles and paradigms that legitimise these approaches. In this chapter, the researcher set to define and outline the research paradigm (Section 3.2) and design (Section 3.3) which were used in collecting and analysing data to answer the research questions (Section 3.4). The participants in the study were Year 8 and Year 11 chemistry students and their details are presented in Section 3.5 followed by a discussion of ethical procedures implied in this research study (Section 3.6).

To answer the research questions, both qualitative and quantitative data were collected using several tools (Section 3.7) which were then analysed by using various statistical techniques (Section 3.8). To establish the validity and reliability of the research findings, data triangulation approach was used (Section 3.9). The chapter concludes by providing links between the research questions, data sources and analysis procedures (Section 3.10) followed by its summary (Section 3.11).

3.2 Research paradigm

A paradigm is a “set of common beliefs and agreements shared between scientists about how problems should be understood and addressed” (Kuhn, 1962). In educational research a paradigm helps orient the researcher towards methodologies and methods appropriate to the paradigm. Researchers have developed many paradigms and different approaches to research (Anderson & Arsenault, 2005). A post-positivist paradigm is a modified scientific method for social sciences which has emerged from positivism (Lincoln & Guba, 1985) and is considered difficult to generalise to real classrooms and schools (Tekin & Kotaman, 2013). Post-positivists involve all the stakeholders in the educational system including teachers, parents, students and administrators as equal partners who work together to reform the education system. According to Tekin and Kotaman (2013), teachers are the best researchers as their knowledge base can be used to find solutions to educational problems. The teacher and researcher roles are always under review so that the researcher should be reflective on their own practices (Phillips & Carr, 2009). As mentioned by Creswell (2009), post-positivists begin with a theory, then they collect data which either supports or refutes the theory from which they make essential changes after which additional tests are performed.

The present study is based on the teacher as a researcher post-positivist approach because the researcher is the teacher who carried out this research study to reflect on her teaching practices in order to enhance student learning (Segal, 2009; Tyce, 2015). A positivist approach requires the researcher to be an independent observer who is impartial to the study findings and subject. However, a teacher as researcher model brings this separation into conflict (Cohen et al., 2011). As stated by Illing (2013), post-positivists aim to address this conflict by collecting data using both quantitative and qualitative methods in natural settings. The quality is assessed by ensuring there is reflexivity in the research through open sources of data with established reliability and validity. In the present study, the researcher collected data using extrinsic sources such as curriculum, school-based norms etc. and intrinsic sources such as established instruments with known characteristics. In addition to these sources, care was taken where necessary to avoid power imbalance when asking for assent or consent, in regards to third parties engaging with participants.

3.2.1 Action research in this study

This researcher as a teacher has noticed in her many years of teaching that students tend to lose interest in science in the classroom and those who are engaged in doing worksheets and activities might not understand the concepts at a deeper level. POGIL a student-centred method, based on the Karplus learning cycle approach has proven to be successful in different classroom settings to improve students' cognitive and affective development (Şen et al., 2016; Vishnumolakala et al., 2017). The researcher decided to use the POGIL pedagogy to teach the chemical science unit to her Year 8 class, and the acid-base concept unit to her Year 11 chemistry class in the hope of improving students' educational outcomes. In the present action research design (Williamson et al., 2002), with teacher as a researcher model, the researcher has integrated this study across multiple year groups. Two distinct studies were conducted over a period of three and half years involving students from different cohorts and year levels (Year 8 and Year 11) to determine the impact of POGIL on the students' learning achievements and their perceptions about POGIL. The validity of action research in schools has been established by many studies (Hudson, 2018; Karadag & Yasar, 2010; Tyce, 2015). In context with the present study, the action research model is appropriate based on researcher's dual role and the nature of the research questions.

3.3 Research design

In educational settings, questions can be addressed through research methods such as collecting and analysing data. A research method is the system of steps taken to study a particular phenomenon or set of phenomena using tools or instruments whereas the methodology is the system of assumptions which determines the appropriate method to be used (LeBlanc, 1995). The intervention for the present study is based on social constructivism (Vygotsky, 1981) and the learning cycle approach (Kode & Cherukuri, 2014) with the main focus to investigate the effectiveness of POGIL — a student pedagogy — on students' understanding of chemistry concepts.

Both qualitative and quantitative data are widely used in educational research studies (Bhattacharyya & Bodner, 2005; Bodner et al., 1999) with careful consideration about the data collection methods and choice determined by the research questions

(Creswell, 2009). Quantitative data can be used to examine the relationship between different variables and is measurable. Qualitative researchers collect data in the natural setting to uncover trends and look deeper into the educational problem (Wyse, 2011). Qualitative data are exceedingly diverse in nature and different tools such as participants' observation, unstructured interviews and direct observations are most commonly used for collecting such data (Cohen et al., 2011). In recent times, it is common to utilise both a qualitative and quantitative approach in the same study as they complement each other by overcoming the weaknesses in individual methods. As stated by Amaratunga et al. (2002), a mixed-method approach is appropriate when it can cover all the components of the research and there is less chance of missing any available data.

Due to the complex nature of the research questions and small sample size in the present study, a mixed methods approach was adopted in this study and both questionnaires and semi-structured interviews were used together which are based on post-positivist approach (Creswell, 2009). A similar study was conducted by Bowman and Standiford (2015) to examine the effectiveness of an educational role-playing (edu-larp) intervention into the science curriculum of an independently operated public school. The data were collected using classroom observations, diagnostic tests and school-based tests to measure students' understanding of concepts; students' surveys and interviews were used to measure students' perceptions of the learning environment.

The present study uses quasi-experimental and pre-experimental design, which is typical of post-positivist studies because participating classes were not chosen randomly (Mitchell & Jolley, 2010). Randomisation is not always a suitable option especially in cases where the sample size is not very large (Harris et al., 2006). In educational settings it is impossible for the researcher to form random groups due to the fixed nature of the classroom settings and concerns about treating only some selected students with a potentially beneficial teaching pedagogy whereas others subjected to less beneficial methods (Cor, 2016).

The Year 8 study includes a pre- and post-test two-group design (Slavin, 2007) to determine the impact of a student-centred teaching pedagogy (POGIL) on students' learning achievement and their perceptions about POGIL.The experimental group used POGIL-based worksheets incorporated in their lessons and the control group was taught using a traditional teacher-centred pedagogy. All students were taught the same chemistry topics through the Year 8 curriculum for Western Australian schools. The control group was taught chemistry through the standard grade curriculum for Western Australian schools. The experimental design for the Year 8 study is discussed in detail in Chapter 5, Section 5.2. The Year 11 study includes a pre- and post-test one-group design and was completed in two years with only an experimental group which received the POGIL intervention. In Chapter 6, the experimental design for the Year 11 study is discussed in detail. The combination of Year 8 and Year 11 study together will be utilised in chapter 7 to discuss the research questions.

The layout of the research design for the Year 8 and Year 11 studies is presented in Figures 3.1 and 3.2. As presented in the figures, the four research questions that emerged from the research framework take the suitable approach for the exploration of POGIL in secondary science classes.

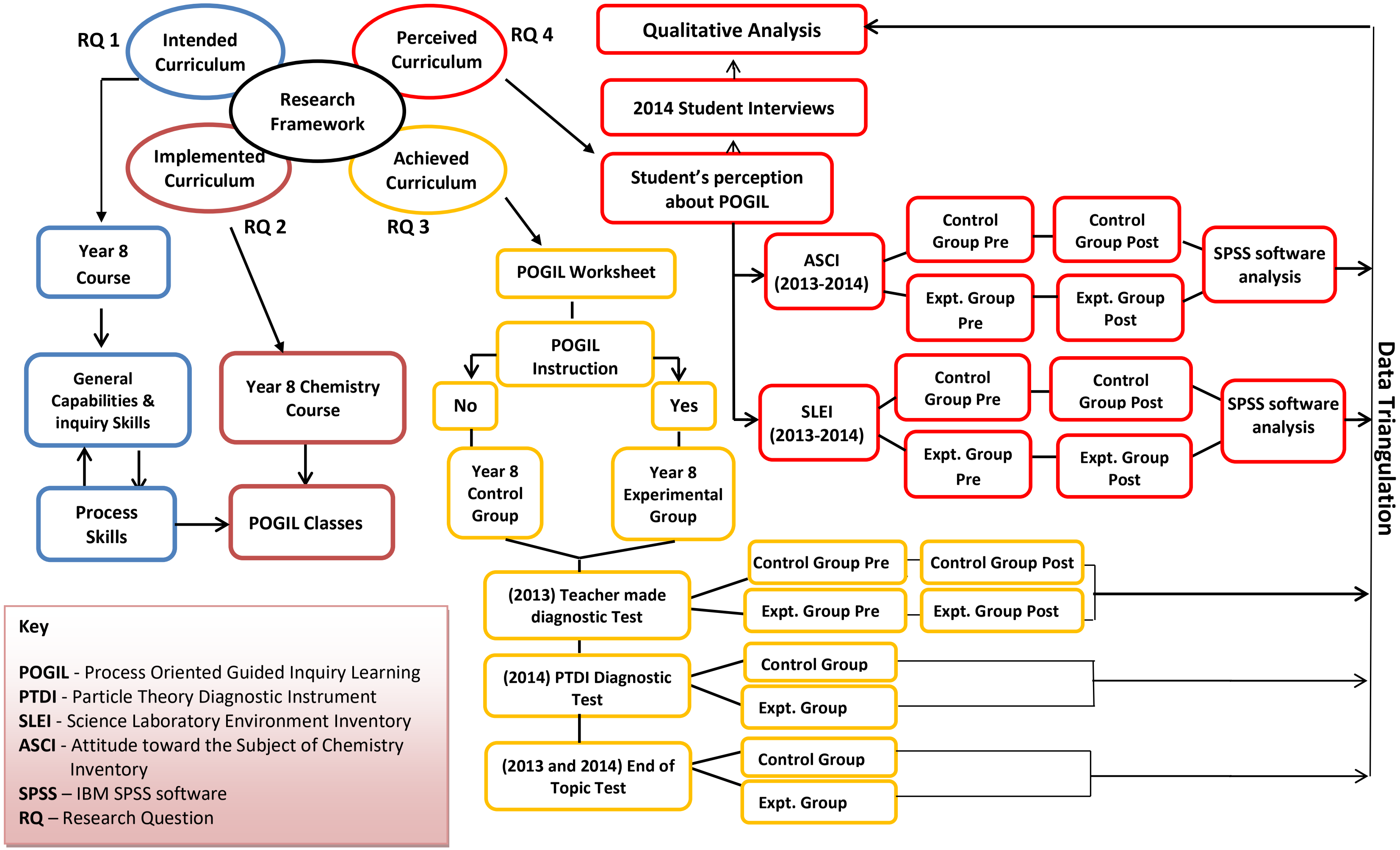


Figure 3.1: An outline of the Year 8 research design adapted from Vishnumolakala (2013)

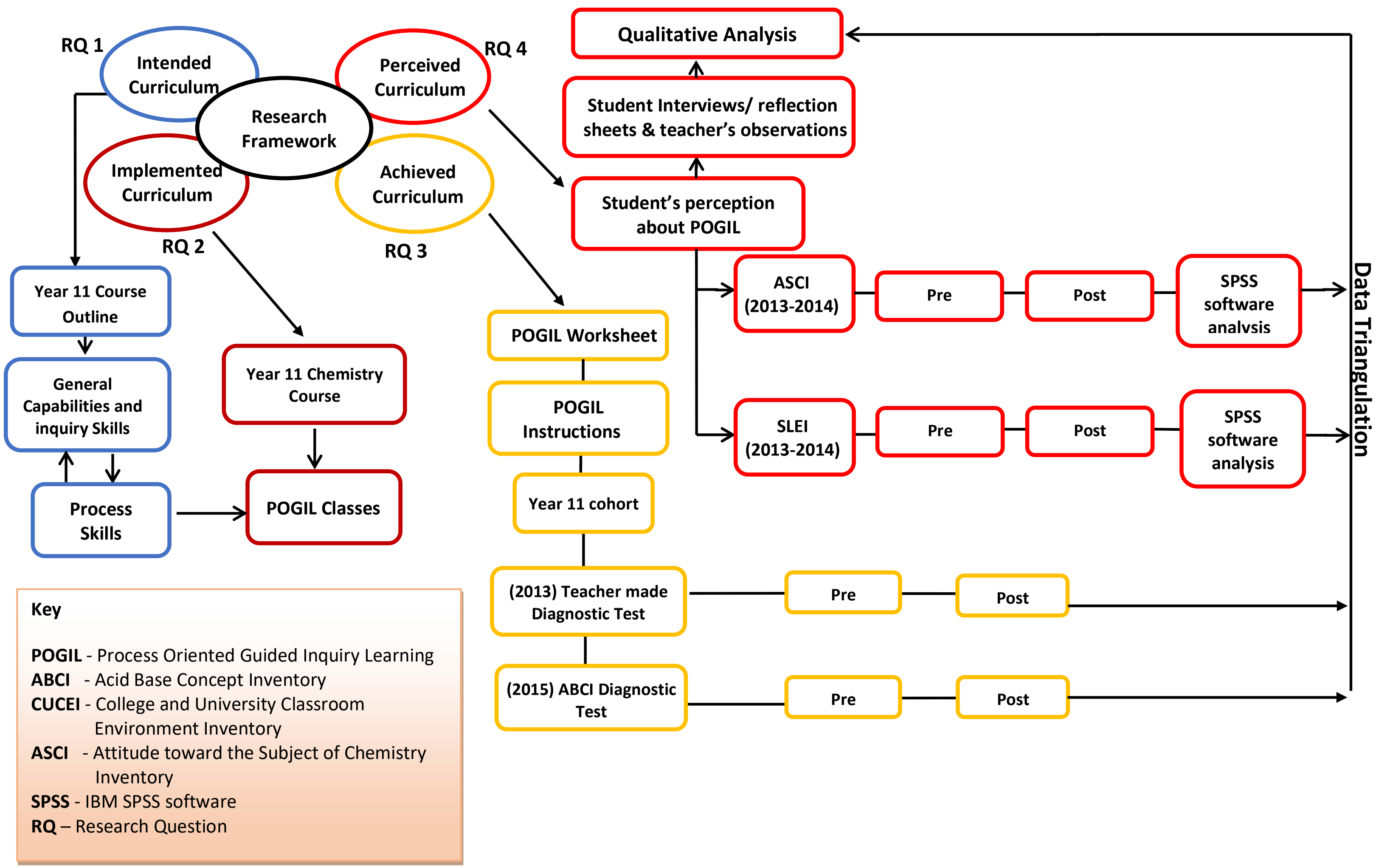


Figure 3.2: An outline of the Year 11 research design adapted from Vishnumolakala (2013)

3.4 Research questions

This study examined the effectiveness of POGIL — a student-centred pedagogy — on the learning of secondary science and senior secondary chemistry students. The research questions to be answered are:

Research question 1: Is POGIL a good match with the existing intended Australian science curriculum?

Research question 2: Is there any evidence that POGIL is culturally transferable to an Australian science classroom and can be implemented to address its curriculum?

Research question 3: Are there any differences in students' achievement in selected diagnostic tests and school-based tests in chemistry after the teaching intervention?

Research question 4: What are students' perceptions about the POGIL lessons?

3.5 Description of the study site, sample and duration of the study

This action research was conducted at a public senior high school located in the metropolitan area of Perth, Western Australia. The school was typical of many throughout Western Australia and included students from Year 7 to Year 12 with science being compulsory for all students in Years 7–10. The data collected for this study comes from Year 8 science class students and Year 11 chemistry students enrolled at the school during 2013 to 2015. The classes were drawn from the researcher's usual teaching allocation; the Year 8 study included a control group for each year from a colleague's class. The presence of a control group provides a reliable data for comparing the results.

Each class had four science lessons a week and each lesson was of 60 minutes duration. The Year 8 study started in the first term of the first semester (Feb – July 2013) and was conducted in two cycles. The participants in the first cycle were 48

Table 3.1: Number of participants and duration of each cycle of the action research

Group	Number of participants		Length of interventions
Year 8 study	1st cycle	n = 48	10 weeks (2013)
	2nd cycle	n = 52	10 weeks (2014)
Year 11 study	1st cycle	n = 16	7 weeks (2013)
	2nd cycle	n = 17	7 weeks (2015)

Year 8 students of two different cohorts. The second cycle for the Year 8 study was conducted in the first term of the first semester in 2014 (Feb – July 2014) with 52 Year 8 students of different cohorts. In the first cycle of the Year 8 study, the participants included 24 boys and 24 girls. The students in both classes were at similar academic and behavioural levels. In the second cycle of the Year 8 study, the participants included 26 boys and 26 girls. The students were of mixed achievement but the majority were average achieving students.

The first cycle of the Year 11 study started in third term in 2013 (July – Sept 2013) and the participants were 16 Year 11 chemistry students from one class. The second cycle was conducted in the third term of 2015 (July – Sept 2015) and the participants were 17 Year 11 chemistry students. Both Year 8 and Year 11 studies were conducted in two cycles as outlined in Table 3.1.

3.6 Ethical procedures

All research that is outlined in the current study involves humans. The relationship between researcher and research participant is the ground on which human research is conducted. As mentioned by AARE (n.d.), research in education must be directed towards general welfare and development of human good. It is very important to consider ethical issues in every phase of the research study (Denzin & Lincoln, 1994; Eybe & Schmidt, 2001) starting from choosing a research topic, population, during the fieldwork, analysis of the research data, publication of the report and storage of the data. The guiding ethical principle for researchers ensures that the rights, welfare and beliefs of the participants are adequately protected at all times. According to Fraenkel et al. (2012, p. 63), "Every researcher should address three important ethical issues: protecting participants from harm, ensuring confidentiality of research data and the question of deception of subjects".

3.6.1 Before commencement of fieldwork

The researcher started by discussing with her supervisor the ethical issues related to the study. A research proposal was presented to the Graduate Studies Committee and an application was subsequently made to the Human Research Ethics Committee (HREC) at Curtin University. The proposal highlighted the aim of the study, type of data that would be collected, and procedures to maintain participants' confidentiality. As stated by Creswell (2005), a researcher must respect the sites where the research takes place. Keeping this in view, a separate research proposal plan was presented to the Head of Science department and school Principal to seek their approval. After receiving the formal approval from both, the researcher presented the proposal to the Department of Education of Western Australia to seek their approval. Copies of the approved documents for the study are presented in Appendix A.

Students in both the Year 8 and Year 11 study were given the information about the activities related to the research study. Relevant and appropriate information about the research (Appendix B) in compliance with HREC requirements were sent to both students and their parents. This information included the purpose and nature of the research, the methods, the duration of data collection and the storage of data. Students were asked to give their assent and parents were asked to sign consent forms prior to their child's participation in the study. Any queries regarding the study were answered and participants or their parents had the right to remove themselves from the study at any time without any penalties. It was emphasised that participation is voluntarily and that a decision not to participate would not have any adverse consequences so as to prevent the potential students to feel pressured to participate.

3.6.2 During the fieldwork

As a science teacher, the researcher is fully aware of the syllabus that needed to be covered, so it was ensured that there was minimal disruption to students' learning. The activities based on POGIL were incorporated in the lessons as would normally be done with any activities. Details of this process are provided in Chapter 4. In any research that involves human involvement it is very important that the confidentiality of participants is maintained (Anderson & Arsenault, 2005; Creswell, 2005). All documents containing participants' names and data were kept strictly confidential and safely. Only the researcher was privy to the identity of the participants and their level of participation. Selected students were interviewed in the teachers' staffroom during the homeroom time and any attribution of quotations is done through pseudonyms.

3.6.3 After the fieldwork

The data needs to be presented in a courteous and non-discriminatory language (Creswell, 2005). The data must be presented in its true form without any fabrication to mislead people. The participants were not penalised if they withdrew from the research study partway. In the present study, the confidentiality of information was preserved by keeping the questionnaires anonymous and interviews with no mention of names. The data from the study were presented in a cumulative form and thus, unidentified. For qualitative analysis, students were given a random sequential number based on their year group. For example, C11_13 code signifies a Year 11 chemistry student number 13 and 8Sc_3 represents a Year 8 science student number 3. The research data will be stored safely for the statutory period of five years.

3.7 Data collection and sources

The present study employed quantitative and qualitative modes of data collection. A number of testing instruments were used in this research study to answer the research questions. The present section includes information about instruments used for the Year

8 and Year 11 studies.

3.7.1 Quantitative sources

Quantitative data was collected using diagnostic tests to compare students' conceptual gain and using learning environment surveys to compare students' perceptions after the intervention. All students in both Year 8 classes were given the survey and test on the same day. For both the Year 8 and Year 11 studies, pre surveys/tests were administered during the first week and post surveys/tests during the last week of the study. The students were made aware of the purpose of the testing and were advised that their performance in the test had no effect on their class results.

Diagnostic tests have been proven to be good for students who know their subject matter but have fear when it comes to descriptive questions as some questions may be ambiguous or incomprehensible (Lowe, 1991, p. 780). The school where this research study was conducted is located in a low socio-economic area and has many students who have low literacy skills. The researcher decided to use multiple-choice questions diagnostic tests for this study because they are convenient to use and students find it easy to answer as they are familiar with multiple-choice tests (Othman et al., 2008). To conduct the study, the following data collection methods were employed.

3.7.1.1 Matter diagnostic test

For the 2013 Year 8 study, the researcher developed a multiple-choice questions diagnostic test to investigate students' understanding of the chemistry topic on matter. The test consists of 11 items and students were required to choose the correct answer except for item 1 where they were required to demonstrate their understanding of states of matter by providing some examples.

As the researcher had already taught the Year 8 science curriculum, she was aware of the concepts that students find challenging. An experienced science researcher also looked at the questions to check the balance of topics. Items 3 and 4 are an example of the questions in the diagnostic test, and are given in Figure 3.3. The complete test is

3. When 100 mL of water in a beaker boils it:

a) forms a liquid.
b) changes to a solid
c) turns to a gas.
d) changes its chemical properties.

4. A liquid takes the shape of the container because its particles are:

a) very small and sink to the bottom.
b) in fixed position.
c) very close together.
d) able to move past each other.

Figure 3.3: Items 3 and 4 from the Year 8 matter diagnostic test (2013 study)

available in Appendix C.

3.7.1.2 Particle Theory Diagnostic Instrument

The Particle Theory Diagnostic Instrument (PTDI) was used to evaluate students' understanding about the particulate nature of matter. PTDI is an eleven-item two-tier multiple choice instrument proposed and developed by Treagust and Chandrasegaran (Treagust et al., 2011; Treagust, 1988) which covered concepts relating to the kinetic particle theory. To use some robust measures, the researcher decided to use this instrument because it has already been tested and validated with various students ranging from high school to university level (Treagust et al., 2011). Another reason to use this instrument was the presence of distractors in each item, which have been derived from conceptions most commonly held by students and being a science teacher, the researcher is fully aware of this fact. The instrument contains eleven multiple-choice items which ask students to choose a justification for their preferred response for each item. One or more knowledge statements that were identified as necessary for the understanding of basic particle concepts at the high school level were included in each item. The first tier of the item pertains to a knowledge statement while the second tier facilitates the testing of the students' learning at higher cognitive levels (Haslam & Treagust, 1987). The three conceptual categories which are covered in PTDI are:

CC1 (Conceptual category 1): Intermolecular spacing in solids, liquids and gases

CC2 (Conceptual category 2): Diffusion in liquids and gases

CC3 (Conceptual category 3): Effect of inter molecular forces on changes of state

The instrument is based on the scientific ideas about the Particulate Nature of Matter (PNM) as mentioned by de Vos and Verdonk (1996). They are:

1. All matter consists of tiny invisible entities called particles.

2. Motion is a permanent feature of all particles. There is a direct relation between the temperature of an amount of matter and the average kinetic energy of the particles.

3. The empty space between particles in a gas is much larger than that occupied by the particles themselves. Particles of a gas are randomly distributed in an enclosed space.

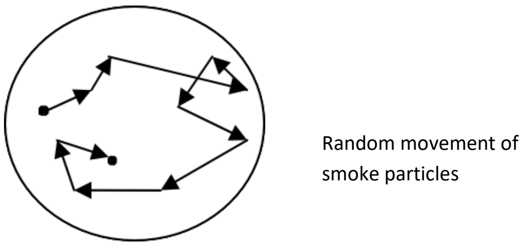
4. There is mutual attraction between any two particles, but its magnitude decreases rapidly with distance. In a gas, the attraction is negligible, except at high pressure and/or low temperature.

5. In liquids and solids, the particles are much closer together and are subject to mutual attraction. In solids, the particles may be arranged in regular patterns, with each particle being able only to vibrate around a fixed position. In liquids, the particles are irregularly arranged and move from place to place within a fixed volume.

Examples of the PTDI items covering an example from each of the three conceptual categories are shown in the Figures 3.4, 3.5 and 3.6. The complete PTDI is available in Appendix C.

Item 1

The diagram represents the random zigzag movement of smoke particles (referred to as Brownian motion) when smoke in a glass container is viewed under a microscope.



What conclusion can you make from this observation?

A Smoke particles are floating in air.

B Air consists mainly of empty space

C Air is made up of tiny particles moving randomly.

D Smoke particles are larger than air particles.

The reason for my choice of answer is:

1 Smoke particles are large.

2 There are large spaces between the smoke particles.

3 Colliding smoke particles move in a random zigzag manner.

4 Air particles are constantly colliding with smoke particles.

5 *Other reason*:……………………………………………………………………

Figure 3.4: Example of a PTDI item in the conceptual category 'Diffusion in liquids and gases' (CC3)

Item 3

When orange juice from a soft drink can is poured into a tall narrow glass, the volume of the liquid remains the same.

A True B False

The reason for my choice of answer is:

1 The particles are able to move about freely.

2 The particles are able to move within a fixed volume.

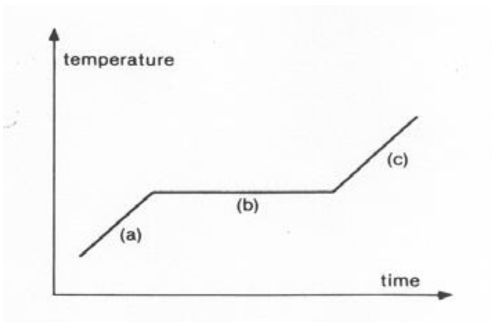
3 Some of the particles may have escaped as the liquid evaporated.

4 *Other reason*…………………………………………………………………

Figure 3.5: Example of a PTDI item in the conceptual category 'Intermolecular spacing in matter' (CC1)

Item 8

The diagram shows how the temperature changes when a solid like naphthalene is heated gently until it melts. In which section of the curve is the heat energy that is absorbed not heating up the naphthalene?



A (a) B (b) C (c)

The reason for my choice of answer is:

1 The energy absorbed is used to break the bonds in the naphthalene molecules.

2 The heat energy absorbed is used to weaken the intermolecular forces.

3 Heat energy is absorbed to increase the kinetic energy of the molecules.

4 Other reason:…………………………………………………………………

Figure 3.6: Example of a PTDI item in the conceptual category 'Influence of intermolecular forces on changes of state' (CC2)

3.7.1.3 Acid-Base diagnostic test

Multiple-choice test papers are very popular among many researchers as they can be applied to a wide range of subjects and can be scored immediately (Moss, 2001). Multiple-choice tests formulated on students' misconceptions make a valuable contribution to the education research (Gurel et al., 2015; Treagust, 1986b) and there is strong evidence to support their validity (Downing & Haladyna, 2006). For the 2013 Year 11 study, the researcher decided to develop multiple-choice questions on acids and bases as these tests can be used to measure different levels of learning and cognitive skills in a short time (Schultz et al., 2017). The strict time constraint that teachers have to follow in order to finish the syllabus also prompted researcher to use this format.

The multiple-choice test consists of 25 questions based on Year 11 chemistry content to check students understanding about "Aqueous solutions and acidity". Some items from the test are presented in Figure 3.7. A complete copy of the test is present in Appendix C.

3. Which is the correct set of acid properties?

A sour taste, corrosive, change litmus from red to blue
B sour taste, corrosive, change litmus from blue to red
C sweet taste, slippery, change litmus from blue to red
D sour taste, slippery, change litmus from blue to red

4. Neutral solutions have a pH of:

A 0
B 7
C 14

Figure 3.7: Items 3 and 4 from Acid-Base diagnostic test (2013 study)

3.7.1.4 Acid-Base Reactions Concept Inventory

After reviewing the results from the 2013 Year 11 study, the researcher decided to use a more robust measure to assess students' conceptual understanding on acids and bases.

A two-tier Acid-Base Reactions Concept Inventory (ABCI) developed by Jensen (2013) was used for the Year 11, 2015 study. Using qualitative data from student interviews ranging from high school to tertiary level, the reasoning questions in ABCI were developed following a bottom-up approach. The original instrument consists of a total of 28 items with 11 two-tier items and 6 single-tier items. For the present Year 11 study, only 11 questions were chosen which are suitable for their year level. Examples of the ABCI items 3 and 4 are shown in the Figure 3.8. The complete ABCI is available in Appendix C.

3) Is this an acid-base reaction?

$$Zn_{\,(s)} + 2HCl_{\,(aq)} \longrightarrow ZnCl_{2\,(aq)} + H_{2\,(g)}$$

Y) Yes

N) No

I chose my answer to question 3 because __________________.

A) A proton is donated and accepted

B) In the reverse direction, H_2 can donate a proton to $ZnCl_2$

C) One electron is transferred to H^+

D) Cl^- donates an electron pair to Zn

4) Is this an acid-base reaction?

$$HNO_{3\,(aq)} + NH_{3\,(aq)} \longrightarrow NH_4NO_{3\,(aq)}$$

Y) Yes

N) No

I chose my answer to question 4 because __________________.

A) HNO_3 bonds to NH_3 to form one product

B) is only one product. There is no conjugate acid or conjugate base

C) a proton is donated and accepted

D) the product will dissociate into spectator ions

Figure 3.8: Items 3 and 4 from Acid-Base Reactions Concept Inventory (ABCI) (Jensen, 2013)

Not only are two-tier tests easy for students to answer, they also provide valuable information to the teachers by offering an insight into students' reasoning and reducing the guess work (Adadan & Savasci, 2012). Jensen (2013) conducted a pilot study using 284 participants from general and organic chemistry to establish the validity and reliability of the instrument. This was the other reason which prompted the researcher to use this instrument.

The first tier is about identifying whether a specific reaction is an acid-base reaction or not. The second tier is about providing a reason as to why they chose that answer. The reasoning questions for the second tier came from student interviews representing many misconceptions held by them.

3.7.1.5 Science Laboratory Environment Inventory

In the Year 8 study, Science Laboratory Environment Inventory (SLEI) was used to measure students' perception of the learning environment (Fraser et al., 1992). SLEI has been developed and evidence of its validity collected in six countries (Australia, United States, Canada, England, Israel and Nigeria) with a range of samples from high school to university students (Fraser & McRobbie, 1995; Fraser et al., 1993; Lee & Fraser, 2001; Wong & Fraser, 1996).

The SLEI consists of five scales, which are Student Cohesiveness (SC), Open-Endedness (OE), Integration (I), Rule Clarity (RC) and Material Environment (ME) as presented in Table 3.2. Each item in the inventory is responded to on a five-point Likert scale which are Almost Never, Seldom, Sometimes, Often, and Very Often which are given scores 1, 2, 3, 4, and 5, respectively, for positive items and reversed scores for the negative items. Any omitted or invalid responses are given a score of 3, the mid-range value.

SLEI has two distinct versions an actual and a preferred, and by assessing both actual and preferred environments a researcher can assess whether the treatment has made any impact on the learning environment. A copy of the preferred version of SLEI is present in the Appendix D. The preferred version measures the classroom environment

Table 3.2: Shows SLEI scales names and with description and attitude towards science scale (Fraser, 1981)

Scale name	Scale description	Sample item	
		Preferred version	Actual version
Student Cohesiveness	The extent to which students know, help and support each other.	I would get on well with students in this science class. (+)	I get on well with students in this science class. (+)
Open-Endedness	To what extent activities focus on open ended divergent approach during the activity.	There would be opportunity for me to pursue my own science interests in this classroom. (+)	There is opportunity for me to pursue my own science interests in this classroom. (+)
Integration	The extent to which laboratory activities are integrated with non laboratory and theory classes.	What I do in our regular science class would be unrelated to my activities. (–)	What I do in our regular science class is unrelated to my activities. (–)
Rule Clarity	The extent to which behaviour in the laboratory is guided by formal rules.	My science class would have clear rules to guide my activities. (+)	My science class has clear rules to guide my activities. (+)
Material Environment	The extent to which laboratory equipment and materials are adequate.	I would find science activities very challenging. (–)	I find science activities very challenging. (–)

perception preferred or liked by the students whereas the actual version measures the perceptions experienced by the students. Both versions have almost identical wording except that in the preferred version the word "would" is used. Table 3.2 highlights the difference in wording between both versions of SLEI questionnaire. High levels of reliability and validity of SLEI have been established by many studies (Fraser & McRobbie, 1995; Gupta et al., 2015; Lee & Fraser, 2001; Quek et al., 2001).

3.7.1.6 College and University Classroom Environment Inventory

College and University Classroom Environment Inventory (CUCEI) was designed by Fraser et al. (1986) to assess students' perceptions. The validity and reliability of CUCEI has been successfully tested by many studies (Fraser et al., 1986; Logan et al., 2006). The present study with two of the researcher's Year 11 Chemistry classes (upper secondary school) is much closer to the POGIL studies conducted at the tertiary level, so some similarities may be apparent. In this study, CUCEI was used for upper secondary Year 11 chemistry class. CUCEI contains seven scales namely: Personalisation, Involvement, Student Cohesiveness, Satisfaction, Task Orientation, Innovation and Individualisation as shown in Table 3.3. The instrument contains 49 statements with seven items belonging to each of the seven scales.

Each item is scored on a four-point Likert scale with the alternatives: Strongly Agree, Agree, Disagree and Strongly Disagree. The items designated (+) are scored 5, 4, 2 and 1. All the 49 items are classified into two groups: positive or negative items. The scoring direction is reversed for about half of the statements designated (–) to prevent students from recognising any pattern to the statements about any particular scale. The items that are omitted or invalidly answered are scored 3. The higher the student scores on the CUCEI, the more positive the student's perceptions of the learning environment. CUCEI also has a preferred and actual version. A copy of the actual version of CUCEI is present in Appendix D.

Table 3.3: CUCEI scales names and with description and attitude towards chemistry (Fraser et al., 1986)

Scale name	Scale description	Sample item
Personalisation	The extent to which students know, help and support each other.	The instructor goes out of his/her way to help students. (+)
Involvement	To what extent student participates actively and attentively in class activities.	The instructor dominates class discussions. (–)
Student Cohesiveness	The extent to which students know, help and are friendly towards each other.	Students in this class get to know each other well. (+)
Satisfaction	The extent to which students enjoy class.	Classes are boring. (–)
Task Orientation	The extent to which class activities are clear and well organised.	Students know exactly what has to be done in our class. (+)
Innovation	The extent to which teacher plans class new unusual activities and teaching techniques.	New and different ways of teaching are seldom used in this class. (–)
Individualisation	The extent to which students are allowed to make decisions are and are treated differently according to their ability and interest.	Students are allowed to choose activities and how they will work. (+)

3.7.1.7 Attitude towards the Subject of Chemistry Inventory, version 2

Attitude towards the Subject of Chemistry Inventory (ASCI) was originally designed by Bauer (2008) and was further revised by Xu and Lewis (2011) to measure students' attitudes towards chemistry. The revised version of ASCIv2 contains eight semantic differential items loading on two latent variables — intellectual accessibility and emotional satisfaction. Each item should complete the sentence "Chemistry is...". Each item score ranges from 1 to 7 with 4 being the middle point. A copy of ASCIv2 is present in Appendix D.

Table 3.4: Items from ASCIv2 (Xu & Lewis, 2011)

Item	Chemistry is...	
1*	Hard	Easy
2	Complicated	Simple
3	Confusing	Clear
4*	Uncomfortable	Comfortable
5*	Frustrating	Satisfying
6	Challenging	Unchallenging
7*	Unpleasant	Pleasant
8	Chaotic	Organised

As shown in Table 3.4, items 1, 4, 5 and 7 are negatively worded and items 2, 3, 6 and 8 are positively worded. The negatively worded items (marked with an asterisk) are reversely coded so that the score analysis for all the items is same and easy to interpret. This means, the lowest score of 1 on the original data is transformed to 7, and the highest score of 7 is changed to 1, and so on. The subclass "Intellectual Accessibility" consists of items 1, 2, 3 and 6 whereas "Emotional Satisfaction" consists of items 4, 5, 7 and 8. The reliability and validity of ASCIv2 has been successfully established in various studies (Bauer, 2008; Brandriet et al., 2011; Vishnumolakala et al., 2017; Xu, 2014; Xu et al., 2014; Xu & Lewis, 2011). ASCIv2 is an appropriate instrument for the Year 11 study as it deals with the mature adolescents. However, the researcher decided to use it for the Year 8 study to look for an interesting comparison.

3.7.2 Qualitative sources

Qualitative data was collected using student reflection sheets and semi-structured interviews to provide more depth about students' beliefs, feelings and motivations regarding POGIL activities.

3.7.2.1 Reflection sheets

In both the Year 8 and Year 11 study, SII reflection sheets (Wasserman & Beyerlein, 2007) were given to the students at the end of each POGIL activity to reflect on the POGIL pedagogy, POGIL worksheets and the process skills. According to Cole and Bauer (2008), the assessor should define the objective and outcomes of what will be assessed so that students can provide feedback only on specific areas of concern. The SII format consists of three phases as described:

Strengths: Identify strengths about the topic and explain why it is a strength.

Improvement: Identify an area of improvement and how it can be improved.

Insight: Identify new understanding gained about the topic.

Students may require some development of skills to complete the SII reflection sheets, so it is advisable to complete some preliminary assessments so that they become familiar with the process as well as develop their self-reflective skills (Cole & Bauer, 2008). A copy of the SII reflection sheet is attached in Appendix D.

3.7.2.2 Semi-structured interviews

In the Year 8 (2014 study) and Year 11 (2015 study), some randomly selected students were interviewed by an experienced teacher, other than the researcher, using a semi-structured format suggested by Fontana and Frey (2005). To collect additional qualitative data, semi-structured interviews were conducted with individual students in a casual atmosphere which lasted from 15 to 20 minutes. The students were asked a set of questions which were categorically placed in three sections namely: group work, POGIL worksheets and general. The first section was designed to investigate students' collaborative learning experiences, while the second section focussed on their learning experiences using POGIL worksheets. The last section comprised of general questions to determine the students' overall views about the POGIL pedagogy. A copy of the interview protocol is attached in Appendix D.

3.7.2.3 Teacher notes

Observations allows an individual to document evidence of what is seen and heard and provides the opportunity to monitor or assess a process or situation (Department of Education, 2015). Teachers conduct observations in their classes with an aim to improve their teaching and learning practices (Atkinson & Bolt, 2010). Observations can be structured, semi-structured or unstructured in nature. As explained by the Department of Education (2015), structured observations require use of a pre-tested and validated instrument, semi-structured observations provide guidance for behaviours to be observed, and unstructured observations provide flexibility for recording details of actions and behaviours observed. In the present study, the researcher as a teacher documented unstructured field notes during POGIL activities to observe its implementation, which will be used to address research question 1. The field notes will also be used to collect qualitative data for triangulation purposes to make sense of students' perceptions of POGIL, which addresses research question 4. A copy of the observation sheet is present in Appendix D.

3.8 Data analysis

Statistics is a branch of science that involves planning, designing, collecting data, analysing, drawing meaningful interpretation and reporting of the research findings (Ali & Bhaskar, 2016). Researchers use parametric and non-parametric tests to analyse their data. Parametric tests are used for normal distribution data whereas non-parametric tests are distribution-free tests that are normally used for small data sets (Grech & Calleja, 2018).

Researchers perform different statistical techniques depending upon the number of variables and conduct inferential statistics on the data to make observations about the likelihood in a population or differences between samples in the population (Burnham, 2015). Likelihood in a population indicates how likely a particular population is to produce an observed sample.

In the present study, descriptive statistics was used to summarise and represent data in an accurate way using tables, charts and graphs. Then, inferential statistics were used to make inferences about the larger population from which the sample is drawn. Statistical significance, also known as null hypothesis significance, is the likelihood that a relationship between two or more variables in an analysis is not purely by chance. As stated by Fan (2001), when comparing the effect of an intervention on different groups of students, there is a likelihood that the differences may arise in their means due to a variation in the samples. The statistical significance level of an event is the probability that the event could have occurred by chance (Riffenburgh, 2012). A low level suggests a very small probability of occurring by chance and the event is considered significant.

In the present study, the statistical significance p value, was tested at a critical value of 0.05, i.e., if the p value is smaller than 0.05, the null hypothesis H_0 is considered not viable and is rejected. However, statistical significance testing has some limitations as it relies heavily on the sample size i.e., with a large sample size it is easier to reject the null hypothesis (Falk & Greenbaum, 1995; Fan, 2001). In addition, since the null hypothesis is based on probability, there is a chance of rejecting a true hypothesis leading to Type I error or failure to reject a true hypothesis causing Type II error.

In educational research, effect size has emerged as an alternative to statistical significance (Fan, 2001). According to Coe (2002), " 'Effect size' is simply a way of quantifying the difference between two groups. For example, if one group has had an 'experimental' treatment and the other has not (the 'control'), then the effect size is a measure of the effectiveness of the treatment". Academic achievement can be increased by an effect size of 0.1 just by making small progressive changes. The effect sizes cumulate over time which can lead to significant improvement (Coe, 2002).

In the present study, both statistical significance testing and effect size were used because they complement each other (Fan, 2001; Sullivan & Feinn, 2012). For parametric tests, the researcher used the two most widely known effect size measures: Cohen's d which is the standardised mean difference (Cohen, 1977) and partial eta-squared (η_p^2) which is the proportion of variance (Lakens, 2013). For the non-parametric tests, effect size was calculated by comparing each of the scores in one group to each of the scores in the other as Cliff's δ (Cliff, 1993). The guidelines for interpreting partial eta squared value (Lakens, 2013), Cohen's d value (Cohen, 1977) and Cliff's δ (Vargha & Delaney, 2000) are presented in Table 3.5.

Table 3.5: Effect size values (Burnham, 2015)

Effect Size	Cohen's d	Eta-squared (η_p^2)	Cliff's delta (δ)
Small (Weak)	0.20	0.01	0.11
Medium (Moderate)	0.50	0.06	0.28
Large (Strong)	0.80	0.14	0.43

The means and standard deviations of the appropriate total group of students were calculated and the effect sizes were computed to understand the magnitude of effect of POGIL on the post-test results. According to Fan (2001), a statistical significance accompanied by a large effect size ensures a high degree of certainty that the observed effect is not due to chance and that the effect is meaningful both statistically and practically. Whereas, a medium effect size with statistical significance is very unlikely that the observed effect is due to statistical chance and that the effect is meaningful both statistically and practically.

3.8.1 Response rates

For the 2013 Year 8 study, the researcher used a simple pre-post diagnostic test and a common assessment task to collect data about students' conceptual understanding. However, the data collected from the teacher made multiple-choice questions diagnostic test did not show a statistically significant difference, so for the 2014 study, the Particle Theory Diagnostic Instrument (PTDI) was used. Two Year 8 classes taught by two different science teachers of similar experience were selected. One class was taught this topic using POGIL as the instructional method and the other class was taught using a traditional teaching method. After this, both classes were administered the PTDI and the data were compared to see any difference in students' understanding of the concept.

To collect students' perceptions about the POGIL learning environment, Science Laboratory Environment Inventory (SLEI) and a revised version of Attitude towards the Subject of Chemistry Inventory, version 2 (ASCIv2) survey were used. The summary of Year 8 students who participated in the data collection journey is presented in Table 3.6.

Table 3.6: Summary of the final sample of Year 8 science cohort

Year	Number of Year 8 participants									
	ASCIv2		SLEI		MC test		PTDI		SII	Interview
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Post	Post
2013	48	48	48	48	48	48	–	–	48	–
2014	52	52	52	52	–	–	52	52	52	5

For the 2013 Year 11 chemistry cohort, a multiple-choice test in a pre and post setting was used and for the 2015 Year 11 chemistry class a modified version of two-tier Acid-Base Reactions Concept Inventory (ABCI) was used under the same settings (Jensen, 2013). To collect students' perceptions about the learning environment, the CUCEI and revised version of ASCIv2 were used. The summary of Year 11 students who participated in the data collection journey is presented in Table 3.7.

Table 3.7: Summary of the final sample of Year 11 chemistry cohort

Year	Number of Year 11 participants									
	ASCIv2		CUCEI		MC test		ABCI		SII	Interview
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Post	Post
2013	16	16	16	16	16	16	–	–	16	–
2015	17	17	17	17	–	–	17	16	17	6

A complete copy of all the diagnostic tests and learning environment instruments is presented in Appendix C and D.

3.8.2 Quantitative techniques

The quantitative data was statistically analysed at the 95% ($p < 0.05$) significance level using SPSS (IBM Corp, 2019) to make statistical comparisons. For the Year 8 study, the pre and post-test results of the treatment and control group for both years were analysed using mixed-model Analysis of Variance (ANOVA) to address the pre-existing differences (Cor, 2016) and to take care of any extraneous variable that could differ between the control and experimental groups (Tabachnick & Fidell, 2014). For the Year 11 study, a paired *t*-test was used to test the difference between two paired results. To satisfy the conditions of normality, equal variance, and independence, both samples for comparison must be independently tested from the same population (Kim, 2015).

The PTDI (Year 8, 2014) and ABCI (Year 11, 2015) were two-tier diagnostic instruments used in the present study. For both tests, students' responses to the first tier and combined tiers were first tabulated in a spreadsheet. Students were given points based on the criteria Coştu et al. (2007) presented in Table 3.8.

Table 3.8: Criteria for analysing two-tier test items (Coştu et al., 2007)

First tier	–	Second tier	Categories	Marks
True response	–	True reason	(T–T)	3
False response	–	True reason	(F–T)	2
True response	–	No reason	(T–N)	2
True response	–	False reason	(T–F)	1
False response	–	No reason	(F–N)	0
False response	–	False reason	(F–F)	0
No response	–	No reason	(N–N)	0

The resulting data file was then converted into a SPSS data file and statistically analysed using the Wilcoxon test because the scores recorded were not continuous. The Wilcoxon test is a non-parametric test which can easily accommodate data that have a wide range of variance (Scheff, 2016), especially with a small sample size (Nachar, 2008). Table 3.9 summarises the statistical techniques used for the Year 8 and Year 11 studies.

Table 3.9: Statistical techniques used for the Year 8 and Year 11 studies

Year	Assessment	Number of students	Statistical test	Effect size
Year 8 study				
2013	Matter diagnostic test, two group pre and post-test design	Experimental group ($n = 26$), Control group ($n = 22$)	Mixed-model ANOVA	η_p^2
2014	PTDI, two group pre and post-test design	Experimental group ($n = 24$), Control group ($n = 23$)	Wilcoxon test	Cliff's δ
2013 and 2014	Matter school-based topic test, two group pre and post-test design	Experimental group ($n = 26, 29$) Control group ($n = 22, 23$)	Paired t-test	Cohen's d
	SLEI, two group pre and post-test design	Experimental group ($n = 26, 29$) Control group ($n = 22, 23$)	Mixed-model ANOVA	η_p^2
	ASCIv2, two group pre and post-test design	Experimental group ($n = 26, 29$) Control group ($n = 22, 23$)	Mixed-model ANOVA	η_p^2
Year 11 study				
2013	Acid-base diagnostic test, one group pre and post-test design	Experimental group ($n = 16$)	Paired t-test	Cohen's d
2015	ABCI, one group pre and post-test design	Experimental group ($n = 16$)	Wilcoxon test	Cliff's δ
2013 and 2015	CUCEI, one group pre and post-test design	Experimental group ($n = 33$)	Paired t-test	Cohen's d
	ASCIv2, one group pre and post-test design	Experimental group ($n = 33$)	Paired t-test	Cohen's d

3.8.3 Qualitative techniques

In the current study, qualitative data was collected using SII reflection sheets, semi-structured interviews and teachers' observations. At the conclusion of each POGIL activity, students were given SII reflection sheets. The qualitative data was analysed using a blend of inductive and deductive approaches such as content analysis method to generate patterns and categories to answer the research questions (Cohen et al., 2011). A content analysis involves a comparison of keywords or content followed by the interpretation of the underlying context (Hsieh & Shannon, 2005). With the help of an external auditor, the data was analysed manually to look for the frequencies of similar opinions and then placed under categorises (Alok et al., 2014). The data was then used to identify emerging patterns and recognise trends. In this study, the researcher collected the SII reflection data and field notes concurrently, analysed separately and then amalgamated in the discussion section using students' quotes for data triangulation purposes.

3.9 Quality criteria and research evaluation

Education research embraces an extensive range of research questions; some are well suited to qualitative methods whereas others are compatible to quantitative methods (Bretz, 2008). Both methods have advantages and disadvantages so debates concerning which method is more beneficial obscure a far more important point. It is very important to establish a "good fit" between the research questions and the methodologies (Bretz, 2008). The essential issue in any research is to ensure there is sufficient evidence of reliability and validity, both in the observations and inferences. The researcher believes that data triangulation is a method of improving the reliability and validity of findings collected by using different methods (Bretz, 2008; Lincoln & Guba, 1985) as presented in Figure 3.9.

Triangulation involves cross-checking the consistency of the results obtained at different times and from different individuals, thus increasing the reliability of the con-

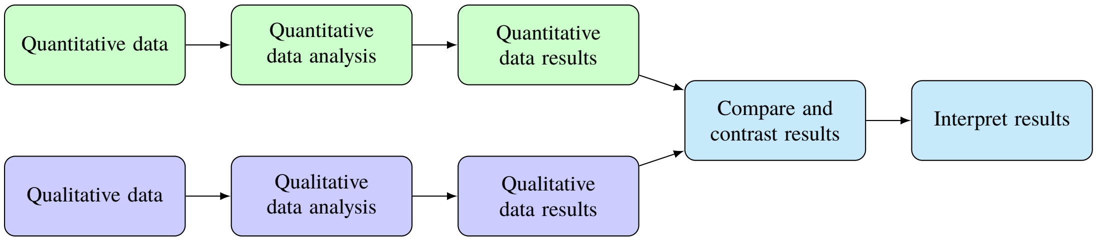


Figure 3.9: Triangulation design convergence model (Taher, 2009)

clusion. As explained by Mathison (1988), the conventional aim of data triangulation was to validate the research findings and the present-day aim is to provide additional information so that the researcher can construct possible explanations about the phenomenon being investigated.

3.9.1 Reliability

Reliability is referred to the degree to which results are consistently achieved over time and the accuracy in total population representation (Joppe, 2000). In other words, if the results of a study can be reproduced under a similar methodology, then the research instrument is considered to be reliable. The reliability in this action research study was ensured by collecting data from multiple sources such as questionnaires, reflection sheets and semi-structured interviews. Interviews were conducted by another chemistry teacher and care was taken to ensure that interviews were consistent all the time. Both the Year 8 and Year 11 studies were repeated for different classes in different years to confirm the reliability and broader application of this study. The data was presented in a MS Excel spreadsheet and analysed using SPSS (IBM SPSS Statistics 26) software.

The internal consistency of each subscale of SLEI, CUCEI and ASCIv2 instruments were calculated as Cronbach's alpha coefficient, which is most commonly used to describe the extent to which all the items in a test which are intended to measure the same construct are closely related (Cronbach, 1951; Heale & Twycross, 2015). Expressed as a number between 0 and 1, if the alpha values are close to 0, the test items are uncorrelated and if it is close to 1, the test items are closely inter-correlated. This provides a measure of reliability. For this research purpose, Cronbach's alpha of greater than

0.7 is considered to be above the satisfactory level and thus each scale is said to have evidence of its reliability (Murphy & Davidshofer, 2005; Shuttleworth, 2016). For the Year 8 study, reliabilities were calculated separately for pre-test and post-test SLEI, for both the experimental and the control group as presented in Table 3.10.

Table 3.10: Internal consistency reliability (Cronbach's alpha) for SLEI scales

Scale name	No. of items	Experimental		Control	
		Pre	Post	Pre	Post
Student Cohesiveness	7	0.76	0.83	0.83	0.75
Open-endedness	7	0.74	0.76	0.83	0.63
Integration	7	0.72	0.88	0.70	0.71
Rule Clarity	7	0.87	0.86	0.72	0.79
Material Environment	7	0.80	0.74	0.74	0.79

The alpha coefficient values for the five scales for both groups ranged from 0.63 for the Open-endedness scale in regards to the control group's post-test, to 0.88 for Integration for the experimental group's post-test. These results indicated that each SLEI scales have acceptable internal consistency and are comparable to past studies (Fraser et al., 1992; Lee & Fraser, 2001).

CUCEI was used only in the Year 11 study and its reliabilities were calculated separately for pre- and post-test as presented in Table 3.11.

Table 3.11: Internal consistency reliability (Cronbach's alpha) for CUCEI scales

Scale name	No. of items	Pre-test	Post-test
Personalisation	7	0.76	0.79
Involvement	7	0.84	0.82
Student cohesiveness	7	0.85	0.80
Satisfaction	7	0.73	0.85
Task orientation	7	0.76	0.74
Innovation	7	0.74	0.91
Individualisation	7	0.79	0.82

The alpha coefficient values for the seven scales ranged from 0.74 for post-test Task orientation, and pre-test Innovation to 0.91 for post-test Innovation. These findings together suggest that each CUCEI scale has acceptable internal consistency and the data are comparable to those in past studies that have used the CUCEI (Booth, 1992; Fraser et al., 1986; Treagust & Fraser, 1986).

ASCIv2 was used for both Year 8 and Year 11 study. The Year 8 study results for ASCIv2 as presented in Table 3.12, show that the Cronbach's alpha values for all implementations exceed 0.70 except for Intellectual Accessibility pre-test for both groups. The Cronbach's alpha values for all implementations exceed 0.70 except for Intellectual Accessibility pre-test for both groups. This suggests a strong internal consistency for the ASCIv2 which is comparable to the results from the literature (Bauer, 2008; Vishnumolakala et al., 2017; Xu, 2014).

The Year 11 study results for ASCIv2 as depicted in Table 3.12 show that the Cronbach's alpha coefficient for each scale was above 0.70, asserting the reliability of the scales of ASCIv2 (Brandriet et al., 2011; Tavakol & Dennick, 2011). These results are consistent with several prior studies (Bauer, 2008; Xu, 2014; Xu & Lewis, 2011). The Cronbach's alpha value results suggest a strong internal consistency in ASCIv2 and provides evidence that the instrument yields reliable scores in different contexts.

Table 3.12: Internal consistency reliability (Cronbach's alpha) for Year 8 and Year 11 ASCIv2 scales

Study	Scale name	No. of items	Experimental		Control	
			Pre	Post	Pre	Post
Year 8	Intellectual Accessibility	4	0.68	0.75	0.68	0.75
	Emotional Satisfaction	4	0.72	0.78	0.72	0.77
Year 11	Intellectual Accessibility	4	0.87	0.89	NA	NA
	Emotional Satisfaction	4	0.91	0.78	NA	NA

3.9.2 Validity

Campbell and Stanley (1966) have defined two major forms of validity, namely internal and external validity. Internal validity refers to the extent to which we can demonstrate that the effects in a study are due to a treatment cause and not some other factor (McLeod, 2013) and is determined by the level of sophistication of design and extent of control (Walliman, 2001). External validity refers to the extent to which research findings are expected to generalise to other participants, settings etc. (Cor, 2016).

The research design in the Year 8 study allowed the use of a comparison group, thus maintaining the internal validity. The experimental group (taught with POGIL) and the control group (taught with traditional methods) were taught using the same chemistry topics through the Year 8 curriculum for Western Australian schools. The comparison made results more meaningful to investigate if the difference in data is only due to the teaching pedagogy. However, the Year 11 study lacked this comparison, as there was no control group. There was only one Year 11 chemistry class in the school. Various extraneous factors were considered in the present study, which could have affected the results as discussed below.

3.9.2.1 History

History refers to any past or current unplanned event that may influence the outcome of the present research study. To reduce this threat, a concurrent control group is selected. For the Year 8 study, both the control and experimental group are enrolled simultaneously and followed up during the same study period.

3.9.2.2 Selection bias

Selection of sample is a major threat in a quasi-experimental research design because the randomisation of the sample is not possible and could lead to group non-equivalence (Cor, 2016). However, an advantage of this design is that it keeps the participants in natural settings, thus allowing a higher degree of external validity (Dimitrov & Rumrill, 2003). For the Year 8 study, a comparison of Test of Reading Comprehension (TORCH) scores was made to compare homogeneity of students in the control and treatment groups. The researcher attempted to provide a detailed description of the participants in both control and experimental groups as outlined in Chapter 5. For the Year 11 study, there is only one chemistry class so there could be no control group which eliminates the possibility of the biased treatment of classes through the application of an intervention (Thyer, 2012).

3.9.2.3 Statistical regression

Statistical regression which can be a threat to the internal validity of the study refers to a regression towards the mean (Flannelly et al., 2018). When an individual's scores are particularly low or high in a pre-test, it is likely to be closer to the mean. Therefore, subjects with an extremely high pre-test score receive a lower score in the post-test and vice-versa; those with an extremely low pre-test score receive a higher score in the post-test. In the present study, this threat was controlled by using an appropriate statistical tool (Barnett et al., 2004) as discussed in Section 3.8.

3.9.2.4 Design contamination

Design contamination is a major threat in a quasi-experimental research design which occurs when students in the experimental and control groups interact and share the information. For the Year 8 study, this was controlled by administering the pre-test on the same day for both experimental and control groups, and subsequently administering the post-test on the same day a few weeks later. The Year 11 study involves only one group so there is no threat to validity from design contamination.

3.9.2.5 Testing

Testing can also influence the validity of a study. When subjects are given the same test as a pre-test and post-test, there are strong chances that they will perform better second time due to the familiarity with the test. According to Onwuegbuzie (2000), the testing effect is more likely to prevail if the time between the administration of the pre-test and post-test is short. For the Year 8 study, there was a gap of 10 weeks between the pre-test and post-test, whereas for the Year 11 study, a gap of 7 weeks was placed between the two tests. Students were not told of their scores between test points.

3.9.2.6 Triangulation

The validity of the study can be increased by using multiple methods of data collection (Mathison, 1988) because it allows the convergence of results (Creswell, 2005). In the present study, data triangulation was used by utilising a number of data sources and methods that included questionnaires and surveys, student interviews and students' refection sheets. The interviews were conducted to validate the results obtained from questionnaires and surveys.

In addition to these data sources, peer examination took place through discussion with the supervisors to assess the validity and quality of the work. An experienced chemistry educator reviewed the POGIL worksheets written by the researcher. This study used sustained interventions and observations throughout both cycles for each study; continual adjustments were made based on the research findings of the first cycle. For all surveys, students' responses to the questionnaires were entered into a database. The validity of the data was checked by entering it twice and by comparing the two entries for accuracy. The interventions used in the Year 8 science lessons and Year 11 chemistry class were also described in detail in Section 3.7. Similar interventions were conducted in both Year 8 cycles and Year 11 cycles except for PTDI (2014, Year 8 study) and ABCI (2015, Year 11 study).

3.10 Alignment between data sources, analysis procedures and the research questions

The present section focuses on the relationship between the four research questions and their respective data source. To answer research question 1, "Is POGIL a good match with the existing intended Australian science curriculum?", the researcher analysed the

Australian curriculum for science for Year 8 and Year 11 chemistry. The curriculum outcomes and POGIL activities were mapped together to link the relevant science inquiry skills, science understanding and general capabilities and the POGIL process skills that the researcher aimed to address during the implementation process.

To answer research question 2, "Is there any evidence that POGIL is culturally transferable to an Australian science classroom and can be implemented to address its curriculum?", the researcher observed the actual implementation process of POGIL in selected POGIL sessions. Qualitative data was collected from various sources. The relationship between research questions 1 and 2 and the data collection tools is presented in Table 3.13.

Table 3.13: Relationship between research questions 1 and 2 and data collection tools

Research Questions	Data sources	Chapter
RQ1: POGIL adaption to the Australian context	Australian curriculum documents	Discussed in Chapter 4
	POGIL worksheets	
RQ2: POGIL implementation	Students interviews	Discussed in Chapter 4
	Reflection sheets	
	Teacher's observation	

To answer research question 3, "Is there any difference in students' achievement in selected diagnostic tests and school-based tests in chemistry after the teaching intervention?", the researcher analysed diagnostic tests and school-based tests for both Year 8 and Year 11 classes. To answer research question 4, "What are students' perceptions about the POGIL lessons?", several questionnaires, students' reflection sheets and semi-structured interviews were used. The relationship between research question 3 and 4 and the data collection tools is presented in Table 3.14.

Table 3.14: Relationship between research question 3 and data collection tools

RQ	Study	Year	Data sources	Form of data	Chapter
3	Year 8	2013	Matter diagnostic test	multiple-choice test, pre and post	Discussed in Chapter 5
			Topic test	School-based common assessment	
		2014	PTDI	2 tier response/reason test, post only	
			Topic test	School-based common assessment	
	Year 11	2013	Acid base diagnostic test	multiple-choice test, pre and post	Discussed in Chapter 6
		2015	ABCI	2 tier response/reason test, pre and post	
4	Year 8	2013 and 2014	SLEI	5 scales, pre (preferred) and post (actual)	Discussed in Chapter 5
			ASCIv2	2 scales, pre and post	
			SII reflection sheets	Qualitative	
			Teacher's observations	Qualitative	
		2014	Student interviews	Qualitative	
	Year 11	2013 and 2015	CUCEI	7 scales, pre (preferred) and post (actual)	Discussed in Chapter 6
			ASCIv2	2 scales, pre and post	
			SII reflection sheets	Qualitative	
			Teacher's observations	Qualitative	
		2015	Student interviews	Qualitative	

3.11 Summary

This chapter outlined the research methodology and justified the use of a distinct research approach to address each of the research questions. The chapter described the research paradigm, research design, research questions, ethics and a wide range of data collection methods. A summary of the different testing instruments, their sample items and how they were developed was explained. Methods of statistical analysis of the data used in the present study were also presented. In the subsequent chapters, the results of the data collected from different data sources will be analysed, interpreted and presented.

Chapter 4

The Intended and Implemented Curriculum

4.1 Introduction

The present action research study focuses on Australian Year 8 chemical sciences and Year 11 chemistry curriculum in an attempt to answer the first two research questions in the current study. In an attempt to respond to the first research question (RQ1), "Is POGIL a good match with the existing intended Australian science curriculum?", the researcher analysed the key ideas of the Australian science curriculum (Section 4.2) and ACARA's general capabilities (Section 4.3) with a particular focus on Year 8 chemical sciences (Section 4.4) and Year 11 chemistry course (Section 4.5) to determine how the learning outcomes can be linked to POGIL in terms of processing skills (Section 4.6).

To answer the second research question (RQ2), "Is there any evidence that POGIL is culturally transferable to an Australian science classroom and can be implemented to address its curriculum?", the researcher discussed the actual implementation process with an experienced POGIL lecturer and analysed this process for both Year 8 and Year 11 (Section 4.7). This discussion will help situate the purpose and findings of each study in the following chapters (Chapter 5 for the Year 8 study and Chapter 6 for the Year 11 study). Some reflection on the teacher's process to identify, adapt and author POGIL activities aligned with the curriculum will be included followed by summary of the chapter (Section 4.8).

The Australian Curriculum, Assessment and Reporting Authority commonly known as ACARA was established in 2008 with an intent to achieve greater uniformity in determining what all Australian students should learn regardless of what school they attend

(ACARA, 2016). The curriculum is designed to ensure that students develop sound knowledge and understanding of the seven learning areas. Each learning area has a scope and sequence that ensures that learning is ordered appropriately. Studies have concluded that Australia needs a science curriculum which can assist young Australians to become fully equipped and thus fill the growing need of the skilled and capable workforce (Rennie et al., 2001). According to Aubusson (2011), the national science curriculum provides regularity in science education throughout Australia. The present Australian curriculum for science provides an opportunity for students to develop not only the understanding of the scientific concepts and scientific inquiry methods, but also an understanding of science's contribution to our society. It also helps to develop an ability to solve problems and make informed, evidence-based decisions about the present and future applications of science.

In Western Australia, the School Curriculum and Standard Authority (SCSA, 2014) is responsible for integrating Australian curriculum content and achievement standards into their courses. The role of SCSA is to:

- develop and endorse the school curriculum;
- assess student achievement in relation to the curriculum through the administration of standardised testing and Australian Tertiary Admission Rank (ATAR) course examinations;
- certify senior secondary achievement; and,
- report on the standards of student achievement.

4.2 The Intended curriculum

The Australian curriculum provides opportunities for students to develop an understanding of important science concepts and also supports them to develop the scientific knowledge, understanding and skills to make informed decisions in regards to current issues in our society (ACARA, 2016). The curriculum, which aims to provide students

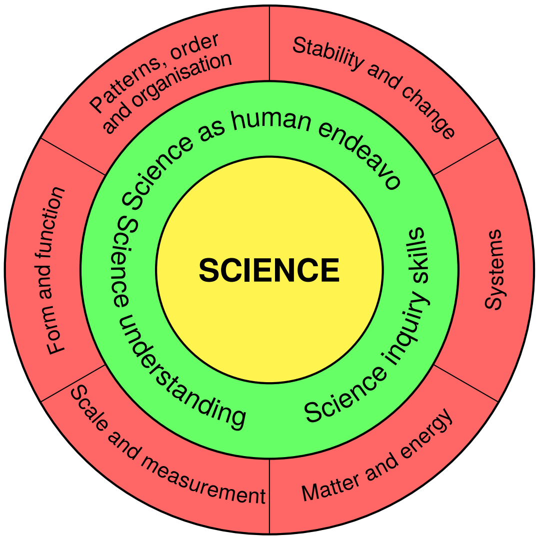


Figure 4.1: Australian science curriculum key ideas (ACARA, 2016)

with an engaging scientific experience as well as challenging them to identify problems and use scientific methods to draw evidence-based conclusions, has six key ideas as illustrated in Figure 4.1. These ideas represent the key aspects of a scientific view of the world and are embedded in each year level description.

These six key ideas are:

Patterns, order and organisation: Recognising patterns and trends, classifying objects and developing criteria.

Form and function: Understanding relationships between the nature or make up of an object and its function.

Stability and change: Recognising that some phenomenon and properties remain constant whereas some change over a period of time.

Scale and measurement: Quantification of time and spatial scale such as huge distances in space, extremely small size of atom etc.

Matter and energy: Identifying, describing and measuring transfers of energy and/or matter.

Systems: Thinking, modelling and analysing in terms of systems in order to understand, explain and predict events and phenomena.

4.3 ACARA's general capabilities and POGIL's process skills

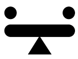
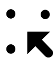
Education has two components, namely, content and process. According to Rillero (1998) it is very important to consider both process skills and content knowledge as equally important, the learning of one aids the learning of the other. These skills are essential in the 21st century and this is emphasised by the Melbourne Declaration on Educational Goals for Young Australians (Ministerial Council on Education, 2008). The process skills often known as essential skills or general capabilities are distinct from any specific learning area capabilities. At schools, students continue to study disciplines in segregation from one other and treat learning as discrete rather than a collective process (Masters, 2015). Keeping this point in view, the general capabilities were incorporated in the Australian curriculum to equip young Australians with the skills which will help them to live and work successfully in the 21st century.

Teachers can incorporate these general capabilities in their teaching where ever possible. However, the curriculum approach of the teachers can differ depending on their understanding of general capabilities (Barrie, 2012). The Australian curriculum intends to develop seven general capabilities of:

1. Literacy
2. Numeracy
3. Personal and social capability
4. Critical and creative capability
5. ICT capability
6. Ethical understanding
7. Intellectual understanding

Overall these capabilities should create successful learners, confident and creative individuals, and active and informed citizens. Table 4.1 outlines the description of these capabilities and it includes a key showing different icons used to represent them.

Table 4.1: Description of ACARA general capabilities (ACARA, 2016)

Icons	Description of general capabilities
	Literacy involves students listening to, reading, viewing, speaking, writing and creating oral, print, visual and digital texts, and using and modifying language for different purposes in a range of contexts.
	Numeracy involves students recognising and understanding the role of mathematics in the world and having the dispositions and capacities to use mathematical knowledge and skills purposefully.
	Critical and creative thinking involves students thinking broadly and deeply using skills, behaviours and dispositions such as reason, logic, resourcefulness, imagination and innovation in all learning areas at school and in their lives beyond school.
	Personal and social capability involves students in a range of practices including recognising and regulating emotions, developing empathy for others and understanding relationships, establishing and building positive relationships, making responsible decisions, working effectively in teams, handling challenging situations constructively and developing leadership skills.
	Ethical understanding involves students building a strong personal and socially oriented ethical outlook that helps them to manage context, conflict and uncertainty, and to develop an awareness of the influence that their values and behaviour have on others.
	Intercultural understanding involves students learning about and engaging with diverse cultures in ways that recognise commonalities and differences create connections with others and cultivate mutual respect.
	Information and Communication Technology (ICT) involves students learning to make the most of the digital technologies available to them, adapting to new ways of doing things as technologies evolve and limiting the risks to themselves and others in a digital environment.

Each of the general capabilities has organised elements and sub elements which construct the learning sequence, emphasising that teachers should provide opportunities to the students to develop these capabilities over time and across learning areas.

In the Australian science curriculum, general capabilities are recognised where they are developed or applied in the content descriptors as shown in Tables 4.3, 4.4 and 4.6 which will be explained in Sections 4.4 and Section 4.5. These capabilities are also identified where there is an opportunity to enhance student learning by providing teachers with techniques on how to teach them.

The POGIL pedagogy and philosophy considers the development of process skills as a significant element of students' learning experiences. The seven process skills identified by the POGIL Project are Communication, Teamwork, Critical thinking, Problem solving, Management, Information processing and Assessment. As stated by Bauer and Cole et al. (2012), POGIL worksheets and a classroom learning environment promotes the development of skills, namely cognitive skills (critical thinking, problem solving and information processing skills) and group process skills (management, communication, teamwork). The intended process skills and identifiable student actions directed to develop these skills during a POGIL lesson are outlined in Table 4.2 (POGIL, 2012).

Table 4.2: POGIL process skills and identifiable student actions

Process Skill	Identifiable student actions
Communication	articulating ideas, exchanging information- rephrasing, reporting and writing using technical skills, and presenting to the class
Teamwork	collaborating with group members, no one left behind, sharing information and building on each other's strengths to achieve a common goal.
Critical thinking	analysing, comparing, synthesising and evaluating to provide reasons to reach a conclusion backed up by evidence.
Problem solving	identifying, accepting challenges, planning and using a strategy to find answers to a problem.
Information processing	evaluating, interpreting and transforming the figures, graphs and data to assess the perception of correct information.

Table 4.2 continued from previous page

Process Skill	Identifiable student actions
Management	coordinating and organising team to accomplish the tasks in time, self management, raising hand and asking questions on behalf of group members.
Assessment	self assessment-reflecting on personal experience and assessment of other students responses to further improve the learning.

As mentioned by ACARA (2016), “The process of building science knowledge is as important as the knowledge itself to develop science inquiry skills”. POGIL can be used to develop Australian secondary science student’s inquiry skills. Science process skills are essential to gain an understanding of the nature of science and science content helps to provide further explanation. POGIL sessions integrate two processes, which occur side by side in the classroom: cooperative learning and constructivism based on inquiry learning as presented in Figure 4.2.

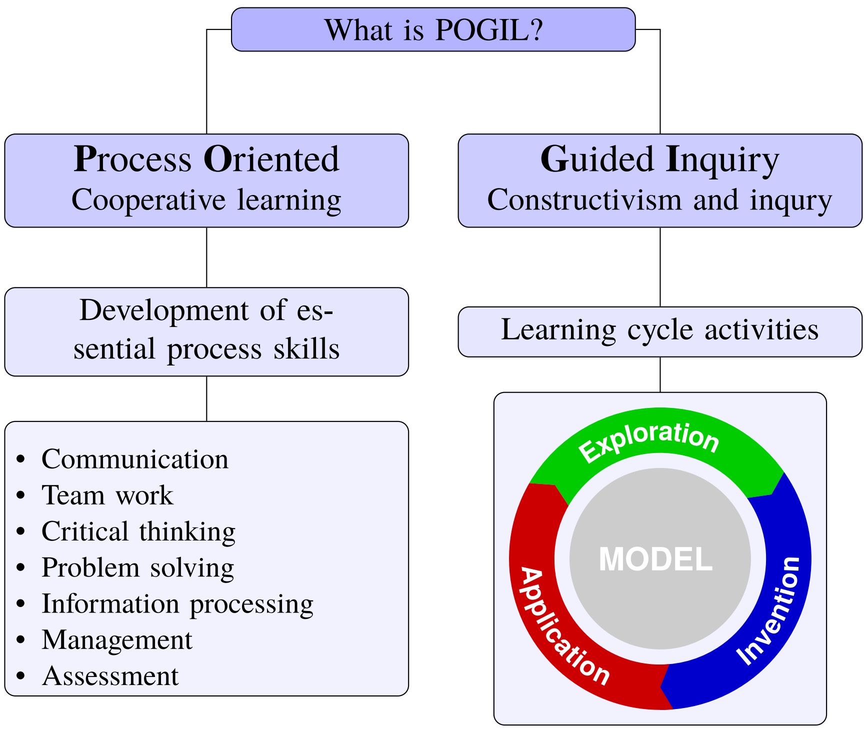


Figure 4.2: What is POGIL? adapted from action research through the trial of appropriate POGIL activities with selected secondary science classes by Wales (n.d.)

POGIL activities provide teachers with opportunities to teach these process skills without compromising the time because the POGIL worksheets can be easily incorporated into lessons. The role of group members are frequently rotated to provide everyone with the opportunity to develop these skills. Coleman and Lang (2012, p. 281) emphasised the importance of a curriculum wide approach to develop collaborative skills and suggested:

> *"We must think intentionally about appropriate places in the curriculum to introduce collaboration skills and recognize that, particularly at the introductory level, these skills are best learned using activities other than traditional group programming experiences".*

As shown in Appendix E, the POGIL worksheets are highly structured and POGIL sessions provide students with the opportunities at various levels to develop the essential process skills.

4.4 Year 8 Science structure

The Year 8 science course consists of three interelated strands: Science Understanding (SU), Science as a Human Endeavour (SHE), and Science Inquiry Skills (SIS).

Science Understanding (SU): This strand delivers content through which significant ideas of science and skills are developed. It involves using appropriate scientific knowledge to explain and predict phenomenon and its application to new situations. SU is further divided into four sub-strands which are:

- Chemical sciences
- Biological sciences
- Physical sciences
- Earth sciences

Science as a Human Endeavour (SHE): This strand covers the development of science and how it influences society.

Science Inquiry Skills (SIS): This strand involves scientific method which is identifying and posing questions – planning, conducting, processing, evaluating and communicating the findings. Science inquiry has five sub-strands which are:

- Questioning and predicting
- Planning and conducting
- Processing and analysing data and information
- Evaluating
- Communicating

Teachers refer to the achievement standard which describe the learning expected of students at each year level and science understanding content for the relevant year to ensure that science as a human endeavour and science inquiry skills are addressed over the two-year period. These three strands are interconnected and taught in an integrated manner. The present study focuses on chemical sciences (SU) and science inquiry skills (SIS) only.

4.4.1 Science Understanding—Chemical sciences

The chemical sciences sub-strand involves understanding the composition and behaviour of substances. As described on the ACARA (2016) website, the key concepts developed within this sub-strand are that: physical and chemical properties of substances are determined by their structure at an atomic level, atoms rearrange to form new substances through atomic interactions and energy transfer. Students classify substances as solids, liquids and gases based on their properties or as elements, compounds and mixtures based on their composition. They further explore physical and chemical changes and recognise that during chemical reactions atoms rearrange to form new substances. As explained on the ACARA website, the chemical sciences curriculum key concepts are labelled as content descriptors ACSSU151, ACSSU152 and ACSSU225, which are further elaborated (ACARA, 2016). Each elaboration has certain general capabilities embedded in them. In this study, we chose the following elaborations with certain general capabilities embedded in them as shown in Table 4.3.

Table 4.3: Elaborations and targeted general capabilities — extracts from the Year 8 chemical sciences course for science understanding (ACARA, 2016)

Content descriptor	Elaboration	General capabilities
Properties of the different states of matter can be explained in terms of the motion and arrangement of particles (ACSSU151)	Explaining why a model for the structure of matter is needed.	
	Modelling the arrangement of particles in elements and compounds.	
	Using the particle model to explain observed phenomena linking the energy of particles to temperature changes.	
Differences between elements, compounds and mixtures can be described at a particle level (ACSSU152)	Modelling the arrangement of particles in elements and compounds.	
	Recognising that elements and simple compounds can be represented by symbols and formulas.	
	Locating elements on the periodic table.	
Chemical change involves substances reacting to form new substances (ACSSU225)	Identifying evidence that a chemical change has taken place.	
	Investigating simple reactions such as combining elements to make a compound.	

Note: The general attribute icons were taken from the web page of ACARA which are explained in Table 4.1.

4.4.2 Science Inquiry Skills

Science inquiry is the process of developing skills which help students to achieve a deeper understanding of the science concepts and application of scientific thinking to these understandings (ACARA, 2016). The process involves identifying and posing questions; planning and conducting an investigation, processing and analysing the results using the evidence, reflecting on the investigation and communicating the findings through appropriate means. The key concepts of science inquiry skills are labelled as content descriptors ACSSU139, ACSSU140, ACSSU141, ACSSU144, ACSSU145, ACSSU146, ACSSU234 and ACSSU148, which are further elaborated with certain general capabilities embedded in them. For the purpose of this study, the following elaborations were chosen as shown in Table 4.4.

Table 4.4: Elaborations and targeted general capabilities — extracts from the Year 8 science course for science inquiry skills (ACARA, 2016)

SIS sub-strand	Content descriptor	Elaboration	General capabilities
Questioning and predicting	Identify questions and problems that can be investigated scientifically and make predictions based on scientific knowledge (ACSIS139)	Using information and knowledge from their own investigations and secondary sources to predict the expected results from an investigation.	
Planning and conducting	Collaboratively and individually plan and conduct a range of types, including fieldwork and experiments, ensuring safety and ethical guidelines are followed (ACSIS140)	Taking into consideration all aspects of fair testing, available equipment and safe investigation when planning investigations.	
	Measure and control variables, select equipment appropriate to the task and collect data with accuracy (ACSIS141)	Using specialised equipment to increase the accuracy of measurement within an investigation.	
Processing and analysing data information	Construct and use a range of representations, including graphs, keys and models to represent and analyse patterns or relationships in data using digital technologies as appropriate (ACSIS144)	Explaining the strengths and limitations of representations such as physical models, diagrams and simulations in terms of the attributes of systems included or not included.	

Table 4.4 continued from previous page

SIS sub-strand	Content descriptor	Elaboration	General capabilities
	Summarise data, from students' own investigations and secondary sources and use scientific understanding to identify relationships and draw conclusions based on evidence (ACSIS145)	Constructing tables, graphs, keys and models to represent relationships and trends in collected data.	
		Drawing conclusions based on a range of evidence including primary and secondary sources.	
Evaluating	Use scientific knowledge and findings from investigations to evaluate claims based on evidence (ACSIS234)	Identifying the scientific evidence available to evaluate claims.	
Communicating	Communicate ideas, findings and evidence based solutions to problems using scientific language, and representations using digital technologies as appropriate (ACSIS148)	Selecting and using appropriate language and representations to communicate science ideas within a specified text type and for a specified audience.	

Note: The general attribute icons were taken from the web page of ACARA which are explained in Table 4.1.

4.5 Year 11 Chemistry structure

The Year 11 chemistry curriculum equips students with the knowledge, understanding and opportunity to investigate properties and reactions of materials (SCSA, 2014). The Year 11 chemistry course also consists of the three interrelated strands: Science Inquiry Skills (SIS), Science as a Human Endeavour (SHE) and Science Understanding (SU) which build on students' learning in the Year 7–10 Science curriculum. The course provides many opportunities for teachers' to incorporate general capabilities in their teaching and learning program, and is divided into two units, each of one semester duration as shown in Table 4.5.

Table 4.5: Year 11 Chemistry course

Unit	Description	Topics
1	Chemical fundamentals: structure, properties and reactions	Science inquiry skills
		Properties and structure of atoms
		Properties and structure of materials
		Chemical reactions: reactants, products and energy change
2	Molecular interactions and reactions	Science inquiry skills
		Rates of chemical reactions
		Intermolecular forces and gases
		Aqueous solutions and acidity

During semester 2, students study unit 2 which has a notional time of 55 class contact hours. Science Understanding (SU) in unit 2 covers three content topics: "Rates of chemical reactions", "Intermolecular forces and gases" and "Aqueous solutions and acidity" (SCSA, 2014). Students develop their understanding of the physical and chemical properties of materials, including gases, water and aqueous solutions, acids and bases (SCSA, 2014). Throughout the chemistry course, students will continue to develop their Science Inquiry Skills (SIS) which are aligned with the Science Understanding (SU) and Science as a Human Endeavour (SHE). The present Year 11 study focuses on the “Aqueous solutions and acidity” topic from unit 2 which covers the topic “solutions” and “Acids and Bases”. General capabilities are embedded in the Year 11 chemistry course content and science inquiry skills as presented in Table 4.6.

Table 4.6: Elaborations and targeted general capabilities — extracts from the Year 11 chemistry course for Science Understanding (SU) and Science Inquiry Skills (SIS) for “Aqueous solutions and acidity” (SCSA, 2014)

Course content	General capabilities
Science Understanding (SU)	
The unique physical properties of water, including melting point, boiling point, density in solid and liquid phases and surface tension, can be explained by its molecular shape and hydrogen bonding between molecules.	
Solutions can be classified as saturated, unsaturated or supersaturated; the concentration of a solution is defined as the quantity of solute dissolved in a quantity of solution; this can be represented in a variety of ways, including by the number of moles of the solute per litre of solution ($mol\,L^{-1}$) and the mass of the solute per litre of solution ($g\,L^{-1}$) or parts per million (ppm).	
The presence of specific ions in solutions can be identified by observing the colour of the solution, flame tests and observing various chemical reactions, including precipitation and acid-base reactions.	
The solubility of substances in water, including ionic and polar and non- polar molecular substances, can be explained by the intermolecular forces, including ion-dipole interactions between species in the substances and water molecules, and is affected by changes in temperature.	
The Arrhenius model can be used to explain the behaviour of strong and weak acids and bases in aqueous solutions.	
Indicator colour and the pH scale are used to classify aqueous solutions as acidic, basic or neutral.	
pH is used as a measure of the acidity of solutions and is dependent on the concentration of hydrogen ions in the solution.	

Continued on next page

Table 4.6 continued from previous page

Course content	General capabilities
Patterns of the reactions of acids and bases, including reactions of acids with bases, metals and carbonates and the reactions of bases with acids and ammonium salts, allow products and observations to be predicted from reactants; ionic equations represent the reacting species and products in these reactions.	
The mole concept can be used to calculate the mass of solute, and solution concentrations and volumes involved in a chemical reaction.	
Science Inquiry Skills (SIS)	
Identify, research and refine questions for investigation; propose hypotheses; and predict possible outcomes.	
Design investigations, including the procedure(s) to be followed, the materials required, and the type and amount of primary and / or secondary data to be collected; conduct risk assessments; and consider research ethics.	
Conduct investigations safely, competently and methodically for the collection of valid and reliable data, including: the use of devices to accurately measure temperature change and mass, flame tests, separation techniques and heat of reaction.	
Represent data in meaningful and useful ways, including using appropriate graphic representations and correct units and symbols; organise and process data to identify trends, patterns and relationships; identify sources of random and systematic error and estimate their effect on measurement results; and select, synthesise and use evidence to make and justify conclusions.	
Interpret a range of scientific and media texts, and evaluate processes,claims and conclusions by considering the quality of available evidence; and use reasoning to construct scientific arguments.	
Communicate to specific audiences and for specific purposes using appropriate language, nomenclature and formats, including scientific reports.	

Note: The general attribute icons were taken from the web page of ACARA which are explained in Table 4.1 of this chapter.

4.6 POGIL and Australian curriculum

This section is about the intended curriculum and addresses the first research question (RQ1), "Is POGIL a good match with the existing intended Australian science curriculum?" Both, the Year 8 and Year 11 chemistry POGIL worksheets were aligned with the Australian curriculum in an attempt to answer research question 1.

4.6.1 POGIL worksheets and Year 8 Chemical science curriculum

Six worksheets based on the POGIL design were used for the Year 8 experimental cohort over a period of 10 weeks, as follows:

1. Matter
2. The particle theory
3. Changes of states of matter
4. Physical and Chemical Properties
5. Pure substance or mixture
6. Classify

Each worksheet was designed to be completed by students in a 50 minute class. All worksheets, except for activity 4, were developed by the researcher. Activity 4, "Physical and Chemical Properties" was adopted from active learning exercises by Marr (2003). These worksheets were reviewed by an experienced POGIL chemistry educator. A copy of the worksheets is attached in Appendix E. Each worksheet starts with some background information about the topic, followed by a success criteria or objectives in dot points, some models and finally the key questions.

The POGIL activities were designed and mapped to the Australian science curriculum carefully, thus covering the science understanding, science inquiry skills and the general capabilities as outlined in Tables 4.2, 4.3 and 4.4. The POGIL worksheets were linked to the Year 8 chemical sciences curriculum as presented in Table 4.7.

Table 4.7: Linking POGIL to the Year 8 chemical sciences Australian curriculum

Topic	POGIL worksheet success criteria	Australian Year 8 Science curriculum
Matter	• Demonstrate the difference between solids, liquids and gases • Use examples to model a particular nature of matter • Comprehend diagrams and information	• Explaining why a model for the structure of matter is needed • Modelling the arrangement of particles in solids, liquids and gases. • Using specialised equipment to increase the accuracy of measurement within an investigation. • Collaboratively and individually plan and conduct a range of types, including fieldwork and experiments, ensuring safety and ethical guidelines are followed. • Drawing conclusions based on a range of evidence including primary and secondary sources. • Selecting and using appropriate language and representations to communicate science ideas within a specified text type and for a specified audience.

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Table 4.7 continued from previous page

Topic	POGIL worksheet success criteria	Australian Year 8 Science curriculum
The particle theory	• Comprehending diagrams and written information • Understand kinetic theory of matter • Applying theory to everyday situation	• Modelling the arrangement of particles in solids, liquids and gases. • Using information and knowledge from their own investigations and secondary sources to predict the expected results from an investigation. • Drawing conclusions based on a range of evidence including primary and secondary sources. • Identifying the scientific evidence available to evaluate claims. • Selecting and using appropriate language and representations to communicate science ideas within a specified text type and for a specified audience.
Changes of states of matter	• Demonstrate understanding of kinetic theory • Demonstrate understanding of different states of matter • Understand that energy is involved with the changes of state • Comprehend diagrams and information	• Using the particle model to explain observed phenomena linking the energy of particles to temperature changes. • Drawing conclusions based on a range of evidence using secondary sources. • Identifying the scientific evidence available to evaluate claims. • Selecting and using appropriate language and representations to communicate science ideas within a specified text type and for a specified audience.

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Table 4.7 continued from previous page

Topic	POGIL worksheet success criteria	Australian Year 8 Science curriculum
Physical and chemical properties	• Explain the differences between physical property and chemical properties. • Explain the differences between physical change and chemical changes. • Comprehend diagrams and information	• Identifying the differences between chemical and physical changes. • Identifying evidence that a chemical change has taken place. • Drawing conclusions based on a range of evidence using secondary sources. • Identifying the scientific evidence available to evaluate claims. • Selecting and using appropriate language and representations to communicate science ideas within a specified text type and for a specified audience.
Pure substance or mixture	• Demonstrate the difference between atoms and molecules • Demonstrate the difference between a pure substance and a mixture • Comprehend diagrams and information	• Modelling the arrangement of particles in elements and compounds. • Drawing conclusions based on a range of evidence using secondary sources. • Identifying the scientific evidence available to evaluate claims. • Selecting and using appropriate language and representations to communicate science ideas within a specified text type and for a specified audience.

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Table 4.7 continued from previous page

Topic	POGIL worksheet success criteria	Australian Year 8 Science curriculum
Classify	• Understand the difference between atoms, elements and compounds. • Comprehend diagrams and information. • Constructing tables to organise data/information. • Classifying substances as elements and compounds.	• Recognising that elements and simple compounds can be represented by symbols and formulas. • Locating elements on the periodic table. • Construct and use a range of representations, including graphs, keys and models to represent and analyse patterns or relationships, including using digital technologies as appropriate. • Drawing conclusions based on a range of evidence using secondary sources. • Identifying the scientific evidence available to evaluate claims. • Selecting and using appropriate language and representations to communicate science ideas within a specified text type and for a specified audience.

4.6.2 POGIL worksheets and Year 11 Chemistry curriculum

Five worksheets based on the POGIL design were used for the Year 11 chemistry class over a period of 7 weeks, as follows:

1. Introduction to acids and bases
2. How do acids and bases behave in water
3. Strong versus weak acids
4. Solubility rules and net ionic equations
5. Reactions of acids and bases

Each worksheet was designed to be completed by students in a 50 minute class. The first three worksheets namely "Introduction to acids and bases", "How do acids and bases behave in water" and "Strong versus weak acids" were adopted from Trout et al. (2012). The worksheet on "Solubility rules and net ionic equations" was adopted from Hanson (2011) and the last activity on "Reactions of acids and bases" was developed by the researcher. It was also reviewed by an experienced POGIL chemistry educator. A copy of the worksheet is attached in Appendix F.

The POGIL worksheets were used as a tool to address the Year 11 chemistry curriculum to cover the topic "Aqueous solutions and acidity". For the Year 11 chemistry class, some selected POGIL activities were mapped to the Australian science curriculum carefully covering the science understanding, science inquiry skills and the general capabilities as outlined in Table 4.6. Table 4.8 highlights the links between POGIL worksheets and the Year 11 chemistry curriculum.

Table 4.8: Linking POGIL to the Year 11 Australian curriculum for chemistry "Aqueous solutions and acidity" topic

Topic	POGIL worksheet success criteria	Year 11 chemistry curriculum
Introduction to acids and bases	• Define an acid and a base according to the Arrhenius and Bronsted-Lowry definition. • Identify acids and bases that illustrate the Arrhenius and Bronsted-Lowry definition. • Explain the acid base properties of amphiprotic substances.	• The Arrhenius model can be used to explain the behaviour of strong and weak acids and bases in aqueous solutions. • Interpret a range of scientific and media texts. • Communicate to specific audiences and for specific purposes using appropriate language, nomenclature and formats.
Strong versus weak acids	• Name the species that makes strong acid strong.	• The Arrhenius model can be used to explain the behaviour of strong and weak acids and bases in aqueous solutions. • Interpret a range of scientific and media texts. • Represent data in meaningful and useful ways, including using appropriate graphic representations and correct units and symbols; organise and process data to identify trends, patterns and relationships. • Communicate to specific audiences and for specific purposes using appropriate language, nomenclature and formats.

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Table 4.8 continued from previous page

Topic	POGIL worksheet success criteria	Year 11 chemistry curriculum
Calculating pH	• Explain why different substances have different pH. • Name the property that is measured using pH probe or with an indicator paper strip.	• pH is used as a measure of the acidity of solutions and is dependent on the concentration of hydrogen ions in the solution. • Interpret a range of scientific and media texts. • Represent data in meaningful and useful ways, including using appropriate graphic representations and correct units and symbols; organise and process data to identify trends, patterns and relationships. • Communicate to specific audiences and for specific purposes using appropriate language, nomenclature and formats.
Solubility rules and net ionic equations	• To be able to correctly predict the products of a double displacement (replacement) reaction. • To be able to the write net ionic equation(s), given the reaction equation.	• Ionic equations represent the reacting species and products in these reactions. • Interpret a range of scientific and media texts. • Represent data in meaningful and useful ways, including using appropriate graphic representations and correct units and symbols; organise and process data to identify trends, patterns and relationships. • Communicate to specific audiences and for specific purposes using appropriate language, nomenclature and formats.

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Table 4.8 continued from previous page

Topic	POGIL worksheet success criteria	Year 11 chemistry curriculum
Reactions of acids and bases	• Being able to correctly write net ionic equations. • Predict the products for acid base reactions.	• Patterns of the reactions of acids and bases, including reactions of acids with bases, metals and carbonates and the reactions of bases with acids and ammonium salts, allow products and observations to be predicted from reactants. • Ionic equations represent the reacting species and products in these reactions. • Interpret a range of scientific and media texts. • Represent data in meaningful and useful ways, including using appropriate graphic representations and correct units and symbols; organise and process data to identify trends, patterns and relationships. • Communicate to specific audiences and for specific purposes using appropriate language, nomenclature and formats.

The POGIL activities intend to develop a mastery of both course content and key process skills by offering a context for both. POGIL worksheets can be successfully incorporated into the existing Australian Curriculum as a learning tool because they address the national standards for content understanding, process skills and science inquiry skills. By integrating POGIL worksheets into their course, teachers can address process skills such as critical thinking and problem solving (Brown, 2010b; Johnson, 2011). A table to illustrate the alignment of the general capabilities and science inquiry skills in the Australian Curriculum and POGIL process skills as evidenced from the observations of POGIL classroom is presented in Table 4.9.

Table 4.9: Alignment of general capabilities and science inquiry skills with POGIL skills in Year 8 and Year 11 chemistry classes

	General capabilities and Science Inquiry Skills	POGIL Process Skills	Classroom observations from POGIL lessons
Communication skills	Communicate ideas, findings and evidence-based solutions to problems using listening, reading, speaking and writing skills to others.	Articulating ideas, exchanging information rephrasing, reporting and presenting to the class.	Students worked on the POGIL activities in small teams with each member assigned a specific role. One student read the question while others listened to him. After this, they discussed the answer and came up to a conclusion. After the completion of the activity, the presenter from each group was asked to answer a key question while other students listened to them. Depending on the answer, the teacher asked some more questions or explained the topic further. At the end of the POGIL activities, students were asked to write their reflections in full sentences.
Interpersonal and social skills	Working effectively in teams, establishing and building positive relationships, handling challenging situations constructively and developing leadership skills.	Planning, organising, directing, and coordinating one's own and other's efforts. Interacting with others and building on each other's individual strengths and skills, to achieve a common goal.	Using pop stick toolkit, a manager was recruited for each group at the start of the POGIL session. The manager ensured that everyone was working together to accomplish the assigned task on time. Some POGIL activities involved laboratory work which also provided POGIL groups the chance to work in teams and collaborate to set up the experiment, take and record observations, clean the apparatus, and indulge in discussions to write the conclusion. Teacher's observation (group 1 and group 2) presented in Section 4.7.3 provide evidence of collaboration and leadership skills.

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Table 4.9 continued from previous page

	General capabilities and Science Inquiry Skills	POGIL Process Skills	Classroom observations from POGIL lessons
Critical thinking and problem solving skills	Apply content related skills, behaviours and dispositions such as reason, logic, resourcefulness, imagination and innovation to discipline specific problem solving.	Plan and use a strategy to find answers, analyse, compare, interpret, synthesise and evaluate to provide evidence based reasons.	As shown in Appendix E, "Changes of state of matter", the key questions require students to use their prior learning. It allows them to explore model 1 and 2 to answer these questions. The CTQs challenged them apply their understanding to different situations. "Acids and bases" worksheet for Year 11 class consists of three models, 1st on Arrhenius theory, 2nd on Brønsted-Lowry theory and the last on conjugate acid-base pairs. Each model is presented with some key questions in a logical sequence and some extension questions at the end (Appendix F).

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Table 4.9 continued from previous page

General capabilities and Science Inquiry Skills	POGIL Process Skills	Classroom observations from POGIL lessons
Summarise data from different sources, interpret information, identify relationships, and draw conclusions. Students use mathematical knowledge and skills purposefully.	Using information to interpret, evaluate and transform the figures, graphs and data, assessing the perception of correct information.	As mentioned above, POGIL worksheets are based on learning cycle approach and intend to develop particular skills in students. For example in Year 8 "The particle theory" worksheet (Appendix E), students are presented with a model and some information about kinetic theory. Further down they are exposed to some key questions where they apply their understanding. As mentioned in ACARA general capabilities are not taught exclusively but they are embedded in the content. In POGIL sessions, also students are not taught information-processing skills separately. As shown in Appendix E "Physical and chemical properties" worksheet, students use the models to differentiate and interpret the difference between physical and chemical property. For the Year 11 study, "Calculating pH" worksheet presents four models with formulas on pH calculations. Students use these models to solve other mathematical problems.

4.7 The Implemented curriculum

POGIL has been implemented successfully in Australia at the university level (Bedgood et al., 2010). However, POGIL implementation at a secondary school level in Australia, has not yet been reported. Staff at Curtin University are among the Australian pioneers of POGIL and the researcher considers she is fortunate to have the chance to work with them. Due to time restraints, she could not attend any POGIL workshops but through intense discussions, reading literature review and watching videos as part of the action research methodology she has obtained an idea of what a POGIL session looks like. Before implementing POGIL, we need to understand the structure of the POGIL worksheet, so the researcher first started by writing POGIL worksheets on chemistry topics suitable for Year 8 levels.

Writing effective POGIL activities with suitable models and questions is a difficult and time consuming process but nowadays the availability of online resources has made the process easier (Abdul-Kahar et al., 2016; Johnson, 2011). POGIL activities are based on the learning cycle concept of exploration, concept invention and application. According to Johnson (2011), the author follows these steps when writing a POGIL activity.

1. Start by writing a clear objective or success criteria which describes the aim of the activity and what students should be able to achieve by the end of the lesson.

2. Create a model in the form of diagrams, information, sentences or some experiments/demonstration so that students can find out the patterns that can lead them to achieve the aim of the activity.

3. Create questions to help guide them through the process. The questions should be of directed, convergent and divergent type (Abdul-Kahar et al., 2016).

    - Directed questions: Usually help students to understand the content of the model; based on the information provided in the model, students should be able to answer these questions.

- Convergent questions: After students have understood the model, they are presented with convergent questions, which encourages students to learn and apply the model.
- Divergent questions: Are critical thinking questions where students apply the knowledge learned, to other situations and require them to understand the content more deeply.

Based on the learning cycle model, usually these questions progress from directed questions, to convergent questions, and lastly, to divergent questions. The time spent on writing these worksheets is worthwhile because once written, they can be modified according to the suitability for the students and can be used indefinitely. A single learning objective or multiple learning objectives can be written in the worksheet. However, it has been advised to not include more than three learning objectives because it becomes over-whelming for students in a typical 50 minute class session (POGIL, 2019).

To answer the second research question, RQ2: "Is there any evidence that POGIL is culturally transferable to an Australian science classroom and can be implemented to address its curriculum", the researcher observed POGIL sessions, used students' Strengths, areas for Improvement, and Insights (SII) reflection data and conducted semi-structured interviews with randomly selected students. Out of six sessions, two sessions were selected to focus on the implementation of the POGIL worksheets as described below. During POGIL session 1, the Year 8 class focussed on "The particle theory" of matter worksheet and during session 2, they focussed on "Changes of states of matter" worksheet.

4.7.1 Activity materials for Year 8

Six POGIL activities were used in the present Year 8 study. The second POGIL activity was chosen for discussion purposes. Activity 2 (Appendix E) used in session 1, on "The particle theory" of matter worksheet starts with some background information explaining the need for the development of the particle theory of matter. This worksheet also requires students having prior understanding of the three states of matter. The success criteria explains the objectives of the worksheet and is written precisely in dot points as represented below.

Success criteria

- *Comprehending diagrams and written information*
- *Providing written points of kinetic theory of matter*
- *Applying kinetic theory to everyday situation*

POGIL activities are designed using questions that guide students through the three phases of the learning cycle: exploration, concept invention, and application. As shown in Figure 4.3, Model 1 consists of a sub-microscopic picture of solid, liquid and gas particles followed by some information explaining the main points of particle of the kinetic theory. It is important that models contain enough depth to allow students to discover the intended concepts themselves. This picture is followed by leading questions designed to guide students toward formulation of their own valid conclusions and requires them to apply their understanding of particle theory. A full copy of the worksheet "The particle theory" is present in Appendix E.

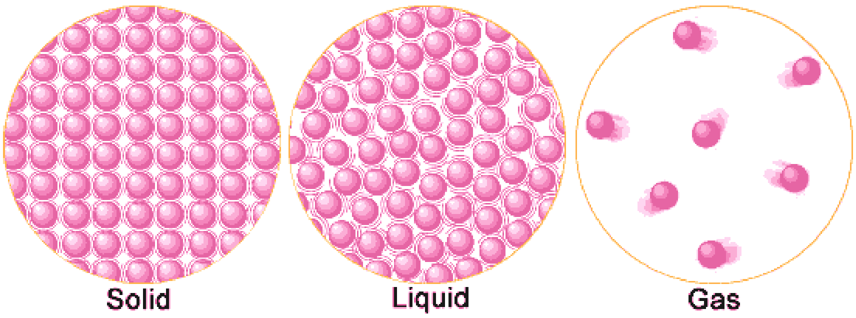
The colourfulness of particles in Model 1 of "The particle theory" worksheet might result in some alternative conceptions as shown in Figure 4.3. This is a potential limitation and will be discussed further in Chapter 7. However, this worksheet was used in a guided inquiry setting where pictorial, symbolic and other forms of representations were provided to the students so the potential for these alternative conceptions is very low.

POGIL Session 1

A typical POGIL session commenced with the teacher asking students to move into their groups and assigning the group roles. After introducing students to the topic, they were handed Activity 2 (Appendix E) "The particle theory" worksheets. Once their memory on states of matters was revitalised by asking some questions, they were advised to

Model 1- kinetic theory

Here are three pictures showing a microscopic view of a solid, liquid and gas.



Note- each circle represents a particle

Key questions

1. Look at the picture of a solid, liquid and gas in model 1.

a) What do you notice about the arrangement of particles in solids?

___

b) What do you notice about the arrangement of particles in liquids?

___

c) What do you notice about the arrangement of particles in gases?

___

Figure 4.3: Model 1 from POGIL worksheet "The particle theory"

read every single piece of information on the worksheet because, the researcher as a teacher had seen that many students skipped the information and straightaway would start answering the questions.

During the entire activity the teacher walked around the room offering students' any advisory help and reminding them to stay focussed. Students seemed to enjoy the first activity and most were engaged as there were some hands-on activities in the worksheet. The only problem was the time management. Students did not stick to the time limit and were slow to finish the activity. Teacher's observations are presented in detail in Section 4.8.2.

In the next lesson, students were given SII reflection sheets and were encouraged to focus on the qualities of the worksheet. Here are some excerpts from the students' SII reflection sheets, highlighting the benefits of the POGIL worksheet:

> *Worksheet is easy to follow through, diagrams are good and clear, majority of the questions are easy, last few questions required us to think more, and every one contributed their ideas to answer the last few questions.*

Some selected students were interviewed to get some deeper insights. The following excerpt illustrates a student reflecting on the merit of the POGIL worksheet. The results from the student interviews are discussed in detail in Chapter 5.

I like pictures, as they are attractive and not boring. They help you visualise the thing and give you hints. The key questions are good as they force you to think about it and apply the knowledge. (8Sc_3)

Based on the students' reflections and researcher's observations, it can be concluded that the majority of the students enjoyed working on the POGIL worksheets. Students found some questions challenging but were able to answer them through group discussions. Students acknowledged the benefit of the POGIL worksheets to actively engage them better in group discussions. Full details of the interviews are presented in Chapter 5.

POGIL Session 2

The focus of this session was the group work. The teacher told the class that they are working on Activity 3, "The changes of states" POGIL worksheet. A full copy of the worksheet is present in Appendix E. Students did not take very long to form into groups and start as they had done this process several times and were familiar with it. After handing out the worksheets, the teacher spent some time going through the three states of matter and their properties to refresh their memories. This worksheet also had some background information, success criteria, objectives and models. The first model, a labelled diagram about phase changes, was followed by some focussing questions and then some new terms were introduced. After question 15, the students were drawn together for a whole classroom discussion in their groups. The teacher invited the presenter from each group to read out the answers while the other students listened to them. The second model provided information about the effect of heat on solids and liquids. Students were directed to attempt the key questions. A few groups managed to attempt a few extra questions.

During the entire session, the teacher wandered around the classroom, pausing and observing each group and guiding them appropriately when needed. The teacher also encouraged discussions between the group members. The class paused again briefly for a whole class discussion and a few concepts were clarified and further explained. As there was not much time left to finish the other questions, students were directed to complete the critical thinking questions in the following lesson. The next lesson, the teacher asked every group to explain their answers to the critical thinking questions to the whole class, thus providing them the opportunity to compare their answers.

Here are some excerpts from the students' SII reflection sheets highlighting the benefits of working in a small group to achieve a common goal and thus support each other's learning:

> *I enjoyed working in groups as you can talk to your friends and get help to answer the hard questions. I am not good in science so it has definitely helped me. Sometimes it is very hard to focus when teacher is talking at*

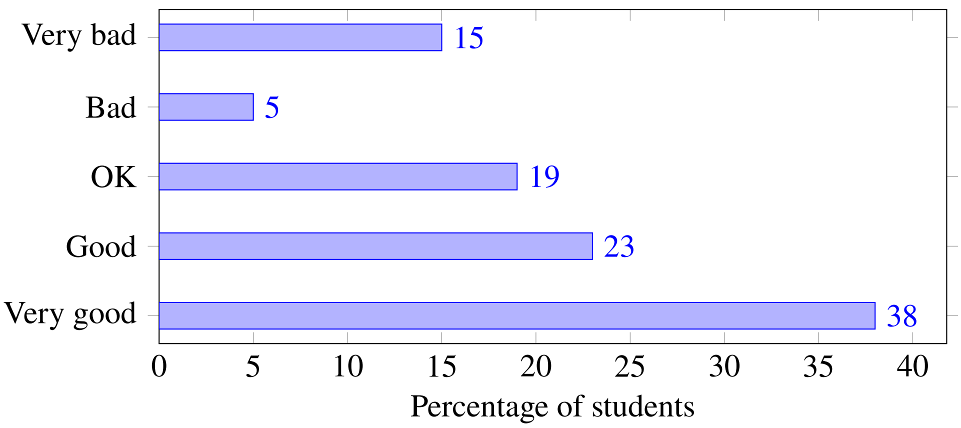


Figure 4.4: Year 8 students' collaborative learning data (n = 100)

the front of the class.

In addition to the reflection sheets, students' were given a Likert scale (Appendix D) at the end of the POGIL session to rate their groups collaborative learning effort as presented in Figure 4.4.

According to the results in Figure 4.4, approximately 60% of the students rated their group's collaborative learning skills high or very high, 19% of the students rated satisfactory and only 20% of the students rated it bad or very bad. These data further support that POGIL can be implemented successfully because a majority of the Year 8 students enjoyed working in a group. Developing a good collaborative rapport is a slow process and once students were habituated to each other and the process, they became more comfortable in their groups.

4.7.2 Activity materials for Year 11 Chemistry

For the Year 11 chemistry class, out of five sessions, one session was selected to focus on the implementation of the POGIL worksheets as described below. Activity 5 "Reactions of acids and bases" was selected for the session. The worksheet follows the same structure as the Year 8 worksheet, starting with some background information as shown below:

Background information

> *Acids and bases have significant roles in our daily life. These roles range from digestion of food in our stomach to destruction caused by acid rain and formation of limestone caves. Acids and bases react with different substances to form predictable products.*

This is followed by some models and key questions as presented in Figure 4.5. A full copy of the worksheet is present in Appendix F.

In Figure 4.5, alternative conceptions may arise as a result of coloured particles being used. This limitation will be further discussed in Chapter 7. Despite the use of coloured particles, the possibility of alternative conceptions is limited due to the implementation of pictorial, symbolic and other modes of representation provided in the POGIL worksheets.

POGIL Session

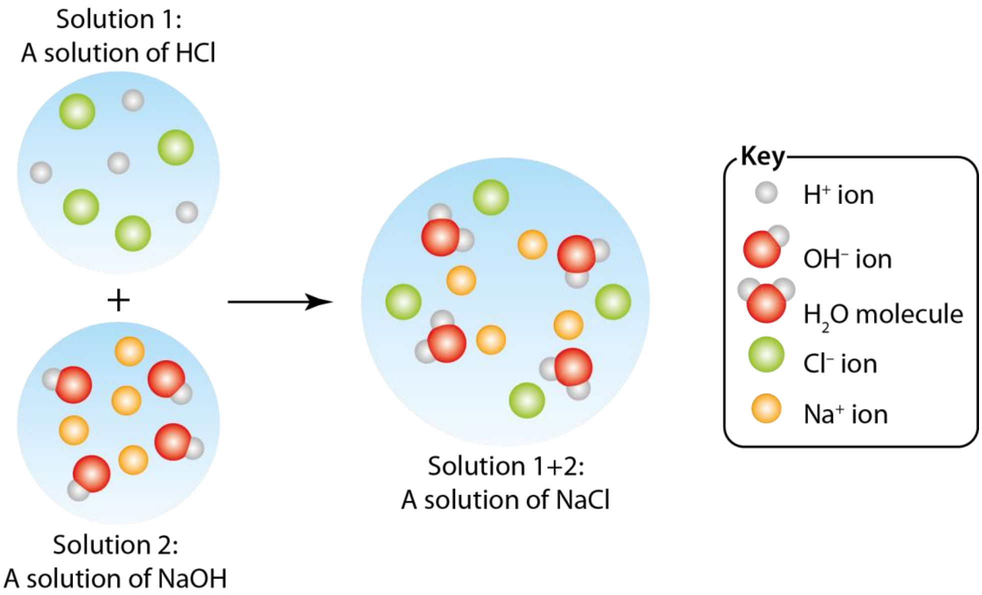
Students were introduced to the topic and were placed in small groups of three. Groups of three worked well for the Year 11 class as the number of students in the class was not very large. They were assigned the group roles and were handed out the worksheet "Reactions of acids and bases".

As this was their last POGIL session, by this time they were very confident about the process and knew what was expected. The teacher moved around during the whole session, guiding students as well as taking anecdotal notes. The majority of the students were focused and working together. One group had to be reminded to discuss with each other to find the answers instead of using the computer. Another student was reminded to be part of the group as he was working on his own.

Selected students were interviewed afterwards and here are some excerpts based on the POGIL worksheet.

> *Some questions were hard since we were not allowed to ask for help and were encouraged to sort it out ourselves. This probably has increased our*

Model 1



Key Questions

a) Name the species present in aqueous solution of HCl in model 1 part (a).

---

b) Name the species present in aqueous solution of NaOH in model 1 part (b).

---

c) Name the species formed when HCl reacts with NaOH:

---

d) Name the species which do not take part in the reaction:

---

e) Write net ionic equation for the above reaction.

Figure 4.5: Model 1 adapted from Quinton et al. (2018) from POGIL worksheet "Reactions of acids and bases"

problem solving ability. You are more focussed with POGIL activities because you are more involved. With teacher talking sometimes you are not focussed. Some members were off task sometimes but deadline helped us stay focussed. A new way of learning adds a bit of variety and got students a little excited about the process. (C11_13)

Another student complimented by saying

Yes, the pictures provided the information to answer the questions. Teacher had projected coloured pictures on the whiteboard which really helped us understand the species present before and after the reaction. The key questions make you think in a logical way. The worksheet starts with easy questions and then kind of become hard. (C11_11)

Similarly, student C11_14 said,

The key questions in the worksheet force you to find a way to answer them without the teacher's help and develop your understanding. (C11_14)

Overall, a majority of the Year 11 chemistry students found POGIL worksheets to be helpful as the implementation of POGIL model contributed to the improvement of student outcomes as well as process skills (Haryati, 2018).

4.7.3 Teacher's observation

During the POGIL sessions, the teacher moved around in the class, pausing and observing each groups discussion and taking notes on POGIL's implementation. Here are some notes from the teachers' observation sheet during the second POGIL session on "Changes of states of matter" in the Year 8 class.

Group one: Students are focussed on the worksheet. Reader is reading out the questions. One student is directed to focus back on the worksheet by the manager.

Group two: Students are discussing Q4. One student directs them to read information from model 2. Everyone is listening while student goes through the points in the model 2.

Group three: This group has more members than the other groups. There is no discussion happening and students are doing their own work. Students are a bit slow to follow through the worksheet. Some students asked if they could change the group as they felt some group members are excluding them.

Group four: Everyone is participating. Students are working at a good pace. They are discussing the answer together and are then writing in their worksheet.

Group five: One student asks for help as he is struggling to write. Another student helps the other student to put the information in a proper sentence. Another student is asking for help to understand the meaning of a word.

Group six: Two students are talking about something else and not doing their work. Rest of the group is doing their work but there is not much discussion happening.

Similarly, the teacher took some notes on POGILs' implementation in the Year 11 chemistry class during the POGIL session on "Reactions of acids and bases".

Group one: Students start working on the worksheet immediately. Everyone is focussed in the group and are participating. One student struggles to use the chemistry data sheet to write observations for the reactions. Another student helps her to use the data sheet.

Group two: Group is focussed and start worksheet immediately. Students are discussing the questions very actively and are helping each other. One student is showing the group how to write an ionic equation.

Group three: This group is merged with another group as few members are absent from both groups. Students are reminded to discuss the questions as they are working on their own. The students are working at a slow pace.

Group four: Students are working on Model 3 but one student is working on a different model. Students are bit talkative and are reminded to stay on the task. They are working on a problem together and discussing the steps.

As evident from the teacher's notes, a majority of students helped each other in group settings and thus developed their speaking, listening and reading communication skills in addition to management and professional skills. Some students have expressed their dissatisfaction regarding groups as they were not used to work in groups. These responses are no different to the views expressed by Li and Campbell (2008) in a study that examines students' perceptions of collaborative learning.

In addition to these observations, some groups had five members which created some time management problems (De Gale & Boisselle, 2015). An attempt was made by the researcher to assign students to appropriate groups; however, it seems more time is needed to set the group norms especially with the Year 8 group. The Year 11 students were more mature and accommodating to each other compared to the Year 8 students and there were less complaints and distractions while working in groups. Students' were challenged by some key questions but with the help of each other, they were able to answer them.

By examining and comparing data from different sources such as teacher's observations, students' SII reflection sheets and students' semi-structured interviews, it was evident that skills required for POGIL learning were implemented and it may have helped these Australian students to develop their science inquiry skills and general capabilities. The results from the student interviews are discussed in detail in Chapter 5 and 6.

4.8 Summary

This chapter focussed on the intended and implemented curriculum by investigating data collected from various sources such as by classroom observations, using students' reflection sheets and by interviewing some students. The first research question (RQ1), "Is POGIL a good match with the existing intended Australian science curriculum?" addresses the implemented curriculum. Both the Australian science curriculum (chemistry) and POGIL process skills were analysed and were found to be aligned with each other, with some skills common to both. By using the learning cycle based POGIL activities, students can improve their science inquiry skills as they learn to examine models/diagrams during the exploration phase. Students will be able to recognise and understand patterns and relationships while practicing problem-solving and critical thinking skills during the invention phase (Johnson, 2011), and lastly, the students can extend and apply the concepts to different contexts during the application phase. POGIL activities further develop students' essential skills (general capabilities) and helps them to prepare for their future life as they learn to apply the acquired knowledge in real life situations (Abdul-Kahar et al., 2016). From the Year 8 and Year 11 chemistry data presented in Sections 4.3 and 4.6, we can clearly see that Australian science curriculum (chemistry), general capabilities and POGIL process skills have common attributes and complement each other, allowing educators to successfully incorporate POGIL worksheets in their teaching program. To address their curriculum requirements teachers can write their own POGIL activities or choose from a pool of online resources.

The second research question (RQ2), "Is there any evidence that POGIL is culturally transferable to an Australian science classroom and can be implemented to address its curriculum?" focussed on the implementation of POGIL in Australian science classrooms. In the present study, the teacher as a researcher model was used and data was collected from multiple sources. The qualitative and quantitative data to support this research question comes from the teachers' observation, the students' SII reflection sheets and semi-structured interviews. Collaborative learning and inquiry based learning forms the basis of POGIL. The analysis of the data strongly supports that the majority of students prefer collaborative learning. Students' feedback was used as part of POGIL's implementation to address the issue of cultural transferability. This will be further expanded under the perceived curriculum to address RQ 4 and will be discussed in Chapters 5 and 6. Students have reported that POGIL has not only improved their conceptual understanding, but also their communication, problem solving and critical thinking questions thus supporting a successful implementation of POGIL. The most common problem faced by the Year 8 students in particular was the lack of desire to engage in group discussions due to the resistance to work with others (Soltis et al., 2015). As mentioned by De Gale and Boisselle (2015), engaging students in POGIL activities has its own challenges which can be overcome by setting clear expectations and creating well-designed activities.

Chapter 5

POGIL in Year 8 Classes — Achieved and Perceived Curriculum

5.1 Introduction

This chapter answers the third and fourth research questions in the context of the Year 8 study by using a quasi-experimental design (Section 5.2) and presenting details about the data collection journey (Section 5.3). To answer the third research question (RQ3), "Are there any differences in students' achievement in selected diagnostic tests and school-based tests in chemistry after the teaching intervention?", (Section 5.4) a series of comparisons between a control and experiment Year 8 class across two years of data collection is presented. The fourth research question (RQ4), "What are the students' perceptions about the POGIL lessons?" (Section 5.5) is addressed by considering student responses to instruments that examine their perceptions of the learning environment and attitudes toward chemistry. These sections are followed by a summary of the data analysis pertaining to the achieved curriculum and perceived curriculum for the Year 8 study (Section 5.6). Lastly, a conclusion of this chapter is presented (Section 5.7).

5.2 Year 8 experimental design

The study took place at the researcher's school, which is a public high school in a low- to mid-socioeconomic status (SES) area (Gosnells, 2021) in south-eastern Perth, Western Australia. More specifically, the school has a significant proportion of students from low-SES backgrounds whose first language is not English and who have low levels of reading comprehension. At the time of this study, Year 8 was the first year of secondary schooling in the school and the first time these students had received subject-based lessons where one teacher teaches a wide range of subject areas, including English, mathematics, science, geography and history to one allocated class.

After receiving approval from the Education Department, the researcher started the study with the Year 8 classes in March 2013. Two Year 8 classes in each of the school years 2013 and 2014 were selected for this study using a quasi-experimental design: a control group and an experimental group. The independent variable was the pedagogy – the traditional teacher-centred learning method and POGIL, a student-centred learning method where students construct knowledge by actively engaging in small group discussions. The students' achievement in chemistry and their perception about the learning environment were measured as the dependent variables. The control group teaching/learning process is carried out so that this can be compared to the POGIL process. This could also provide insight into the comments that students made about their preference for one or other methods, or their struggle to adapt to the different teaching/learning process. As participants cannot be assigned randomly in educational settings, the quasi-experimental design was best suited for this study (Walser, 2014). However, this method had a limitation as there was a chance that external variables like gender, ethnicity, or intelligence could affect the outcome of the results (Fraenkel et al., 2012). It is important to compare groups on a set of relevant characteristics otherwise these pre-existing differences may serve as an alternative explanation for any observed differences among (Cor, 2016).

It is very important that both the control and experimental groups are alike in as many dimensions as possible (Slavin, 2007) so that only the independent variable has its effect. A comparison between both Year 8 groups was made before the intervention, so that the effect of the POGIL pedagogy on the experimental group could be determined. The teachers involved used a common course sequence to ensure that all students were being taught the same chemistry topics based on the same standards; only the pedagogy was different. Both groups received the same learning content, testing instruments and questionnaires. The low- to mid-SES status of the catchment area for the school where this research took place is likely to have an impact on interventions in early adolescent classes caused by variables including language development and sociocultural background of the students.

Reading comprehension was thought to be one variable that could have affected the students' ability to understand POGIL worksheets. Test of Reading Comprehension (TORCH) scores for students from both classes were used to establish the equivalence of both groups, as illustrated in Table 5.1. TORCH is a test designed by the Australian Council for Educational Research (ACER) to help teachers assess students' reading comprehension skills. Students from both classes were administered the TORCH test at the beginning of the school year by an English teacher at the school as part of a broader strategy to assist literacy development at the school. For each year level there were two high achieving classes and the remaining classes comprised of students who had varying levels of reading comprehension skills. The experimental and control groups were each selected from the varying level classes.

Table 5.1: Test of Reading Comprehension (TORCH) scores for Year 8 experimental and control group

TORCH score	2013 Year 8 study		2014 Year 8 study	
	Experimental (n = 26)	Control (n = 22)	Experimental (n = 29)	Control (n = 23)
Acceptable	14	14	13	15
Poor	12	8	14	8
Low comprehension	46.1 %	36.3%	48.2%	34.8%

For the 2014 study for the experimental group, the TORCH scores for two students was not available. Acceptable on the TORCH score is a stanine score of 4 and above.

Reading comprehension is just one measure relating to English literacy. Another factor was the proficiency in the English language caused by acquisition as an additional language and/or communication in the home in a language other than English. Australia is a multicultural country and schools in the metropolitan region of Perth, where this school is located, has many students for whom English is their additional language. It has been reported that English as an Additional Language (EAL) students lack academic success due to their limited understanding of the course content and inability to interact with their peers and teachers (Karanja, 2005). A comparison of the number of EAL students using percentages was made between both groups, in both cycles, in the years 2013 and 2014 as outlined in Table 5.2. In both classes, the difference between the percentages of EAL students is not significant; the experimental group has 23.6% and the control group has 22.2%.

Table 5.2: Comparison of gender and EAL students ratio in Year 8 experimental and control group

Factor	2013 Year 8 study		2014 Year 8 study		Combined Year 8	
	Experimental (n = 26)	Control (n = 22)	Experimental (n = 29)	Control (n = 23)	Experimental (n = 55)	Control (n = 45)
EAL students	7 (26.9%)	5 (27.7%)	6 (20.7%)	5 (21.7%)	13 (23.6%)	10 (22.2%)
Males	11 (42.3%)	13 (59.1%)	15 (51.7%)	11 (47.8%)	26 (47.2%)	24 (53.3%)
Females	15 (57.7%)	9 (40.9%)	14 (48.3%)	12 (52.1%)	29 (52.7%)	21 (46.7%)

Gender ratio is another variable which has different reviews. Some studies have found that gender is linked to a difference in motivation and academic achievement (Freeman, 2004; Musa, 2013), whereas other studies have indicated that gender has no influence on attitude and academic achievement (White, 1999; Zangmo et al., 2016). In a meta-analysis involving 1.6 million students ranging from grade 6 through to university from all over the world, O'Dea et al. (2018) found that gender had no influence on performance in STEM classes. Table 5.2 outlines a comparison of the gender ratio in both groups in both cycles of this study. In the 2013 study, there are 15.4% more females than males in the experimental class whereas the gap is reduced to 3.4% in the 2014 study to 3.8%.

To control these variables, care was taken to select classes with students of mixed abilities so that they had the same level of motivation, interpersonal skills and behavioural problems. Assistance was received from an experienced EAL teacher to choose these classes.

5.3 Year 8 class data collection journey

A series of pre-tests covering the cognitive and sociocultural constructs of interest were administered to both classes before the formal intervention. In the same week, a preferred Science Laboratory Environment Inventory (SLEI) questionnaire (Fraser et al., 1993) and Attitude towards the Subject of Chemistry Inventory, version 2 (ASCIv2) survey (Bauer, 2008; Xu & Lewis, 2011) were administered to students in both classes. The questionnaires were given to collect quantitative data on the environmental contributions to learning and as a baseline measure before the POGIL intervention.

The experimental class was taught using the POGIL method whereas another teacher of similar teaching experience taught the other Year 8 classes using traditional teacher-centred methods. In the experimental class, students worked in small groups on the POGIL-based activities. At the end, students from both the experimental and the control class were given a post- diagnostic test and an end of topic test on matter. The end of topic test is a common assessment task which every Year 8 student is required to do as part of the normal school-based assessment regime. They also repeated the actual SLEI and ASCIv2 surveys. In the experimental class, students were also given reflection sheets at the end of POGIL activities and their responses were grouped into four categories.

The study was repeated in 2014 and again two Year 8 classes were selected. The experimental class was taught by the researcher and the controlled class was taught by an experienced science teacher. Firstly, students from both classes were given the SLEI and ASCIv2 survey. Again, students worked in small groups on the POGIL-based worksheets in the experimental class. At the end of the experimental, students from both classes were administered the Particle Theory Diagnostic Instrument (PTDI), end of topic test, SLEI and ASCIv2 survey. To collect some additional qualitative data, students in the experimental class were given SII reflection sheets at the end of each POGIL activity. Another teacher with similar teaching experience interviewed some randomly selected students in a semi-structured format. The interview protocol and SII reflection can be found in Appendix D. The summary of the data collection journey for the Year 8 study is tabulated in Table 5.3.

Table 5.3: Year 8 study data collection summary

Purpose	Source	Time				
		Pre		During	Post	
		Experimental	Control	Experimental	Experimental	Control
Reading comprehension	TORCH	✔	✔			
Learning environment	SLEI	✔	✔		✔	✔
Attitude	ASCIv2	✔	✔		✔	✔
Subject performance	School-based test				✔	✔
Concept understanding	Researcher-developed test	2013 only	2013 only		2013 only	2013 only
	PTDI	2014 only	2014 only		2014 only	2014 only
Student reflection	SII reflection			✔		
	Semi-structured interviews				✔	

5.4 Achieved curriculum

The achieved curriculum defines the student's academic achievement in the standard tests (Çil & Çepni, 2014; Menis, 1991). For this study, the evaluation of the effect of POGIL activities on students' learning gains were based on three assessments, namely, the topic test on matter, multiple-choice questions diagnostic test on matter, and a two-tier Particle Theory Diagnostic Instrument (PTDI). In this section the achieved curriculum is described and provides the answer to research question 3, "Are there any differences in students' achievement in selected diagnostic tests and school-based tests in chemistry after using POGIL in comparison to teacher-centred learning style?"

5.4.1 Topic test on matter

The first assessment was a school-based end of topic test on the particulate nature of matter. As some questions in the 2014 test were not identical to the questions in the 2013 test, the researcher calculated the mean score based only on the identical questions. Both classes wrote the test under the same test conditions. The combined results for both years are presented in Table 5.4. In both years, the experimental group's mean scores were higher than the control group's mean scores.

Table 5.4: Descriptive statistics for end of topic test for Year 8 experimental and control group for 2013 (n = 48) and 2014 (n = 52)

Group	Year	M	SD	95% CI	
				LB	UB
Experimental	2013	26.08	4.65	24.16	28.00
	2014	23.66	3.84	22.20	25.12
Control	2013	24.23	4.13	22.40	26.06
	2014	20.04	5.91	17.49	22.60

A mixed model Analysis of Variance (ANOVA) was conducted to compare the results of both experimental and the control group. Students who received the POGIL intervention compared to the students in the control group demonstrated statistically significantly better end of topic test results, $F(1, 96) = 9.07, p < 0.05 : \eta_p^2 = 0.09$. The partial eta squared signifies the magnitude of the difference between two means and is considered "medium" according to Lakens (2013) as presented in Table 3.5 in Chapter 3. These results showed that POGIL activities made a positive impact on students' understanding of chemistry.

5.4.2 Matter diagnostic test

The second assessment used was a pre- and post-measure of students' fundamental conceptions of matter with a teacher made multiple-choice questions diagnostic test on the particulate nature of matter; this text was only used for the 2013 student cohort. A mixed-model repeated measures Analysis of Variance (ANOVA) was conducted to examine the effect of POGIL on student learning. The repeated measure was chosen to control the individual student differences in the comparison among the other variables. The results of the test are presented in Table 5.5. The experimental group's mean score increased from 11.42 in the pre-test to 13.12 in the post-test whereas the control group's mean indicated only a slight increase from 12.70 in the pre-test to 12.91 in the post-test.

Table 5.5: Descriptive statistics for 2013 matter diagnostic test for Year 8 experimental ($n = 26$) and control($n = 22$) group

Group	Time	M	SD	95% CI	
				LB	UB
Experimental	Pre-test	11.42	3.44	10.03	12.81
	Post-test	13.12	3.60	11.66	14.57
Control	Pre-test	12.70	2.80	11.45	13.94
	Post-test	12.91	2.47	11.82	14.00

Based on the results of the ANOVA pre-test/post-test design analysis, there was a statistically significant difference between students' achievement in selected diagnostic tests in Year 8 chemical sciences, $F(1, 46) = 13.028, p < 0.05$ results before and after the POGIL model was applied in learning with a medium effect size $\eta_p^2 = 0.12$. The 2013 data showed early signs of some conceptual gains after the POGIL intervention but there was a lack of evidence for reliability and validity which prompted the researcher to use a robust diagnostic tool like PTDI in the 2014 study.

5.4.3 Particle Theory Diagnostic Instrument

As described in Chapter 3, the PTDI (Treagust et al., 2010) was used in the 2014 study. The PTDI data was analysed using criteria developed by Coştu et al. (2007) and summarised in Table 3.8 presented in Chapter 3. The PTDI covers three conceptual categories, each containing some items: Intermolecular spacing in solids, liquids and gases, Diffusion in liquids and gases and the Effect of intermolecular forces on changes of state. Analysis was performed on the explanations given by the students for each PTDI item. The results of this analysis were divided into three parts based on the three conceptual categories of the PTDI items.

The interpretation provides details about which concepts were clearly linked to the purpose of specific POGIL worksheets. As presented in Table 5.6, items 3, 4, 5 and 11 are related to the first conceptual understanding of intermolecular spacing in solids, liquids and gases.

Table 5.6: Comparison of mean scores for first conceptual understanding for PTDI for Year 8 experimental (n = 24) and control group (n = 23)

Item No.	Description	Experimental	Control
3	The volume of a liquid (but not its shape) remains constant as the spacing between the particles is fixed despite the particles moving about randomly	1.88	1.61
4	A gas, unlike a liquid, can be readily compressed because the gas particles are very widely spaced	1.33	1.22
5	The volume but not the mass of a gas decreases on compressing as the widely spaced particles are pushed closer together	1.67	0.83
11	There is a contraction in volume when certain liquids are mixed together as particles of one liquid occupy the spaces between particles in the other liquid	0.96	0.83
Total		5.83	4.48

In the first conceptual category (intermolecular spacing in solids, liquids and gases) students in the experimental scored higher than the controlled group. For item 5, the combined tier score was very high compared to the control group. In the first POGIL worksheet session there was a practical activity that explored concepts similar to PTDI items 4 and 5 as described below.

> *Get a plastic syringe (piston) and fill it with water. Now close the opening using a finger and push the plunger down. What happens?*
>
> *Can you compress (squeeze) water?*
>
> *Now fill the plastic syringe with air. Close the opening using a finger and push the plunger down. What happens?*
>
> *Can you compress (squeeze) gas?*
>
> *Pour some water in a beaker and some in a conical flask. Does water has a definite or fixed shape?*

While doing the second POGIL worksheet "The particle theory", students looked at the kinetic theory of particles in detail and applied that knowledge to everyday situations as presented below.

> *You can compress a syringe filled with air but not with water. How do you explain the difference in the compressibility of air and water? What would you see at the particle level to explain what is going on?*

As mentioned by Treagust et al. (2011), the conception related to this item is that as the volume of gas decreases, the mass remains constant because the widely spaced gas particles are pushed closer together, while the number of particles is unchanged. The POGIL worksheets definitely helped students to understand the intermolecular spacing of particles in solids, liquids and gases. This was followed by the third conceptual category (effect of intermolecular forces on changes of state) which consists of items 8, 9 and 10 as presented in Table 5.7.

The experimental group scored marginally better for items 8 and 9. Both items were about the strength of intermolecular forces during a phase change. Even though the POGIL worksheet did not present information in the diagrammatic form, students

Table 5.7: Comparison of mean scores for third conceptual understanding for PTDI for Year 8 experimental (n = 24) and control group (n = 23)

Item No.	Description	Experimental	Control
8	The temperature remains constant during melting as the heat energy absorbed is used to weaken intermolecular forces and enable the particles to move more freely	1.00	0.91
9	A substance remains in the liquid state at its boiling point until the intermolecular forces have been weakened between all the particles enabling the particles to move more freely	1.13	0.39
10	Heat energy is absorbed during melting and boiling to weaken the intermolecular forces and enable the particles to move more freely	1.46	1.74
Total		3.58	3.04

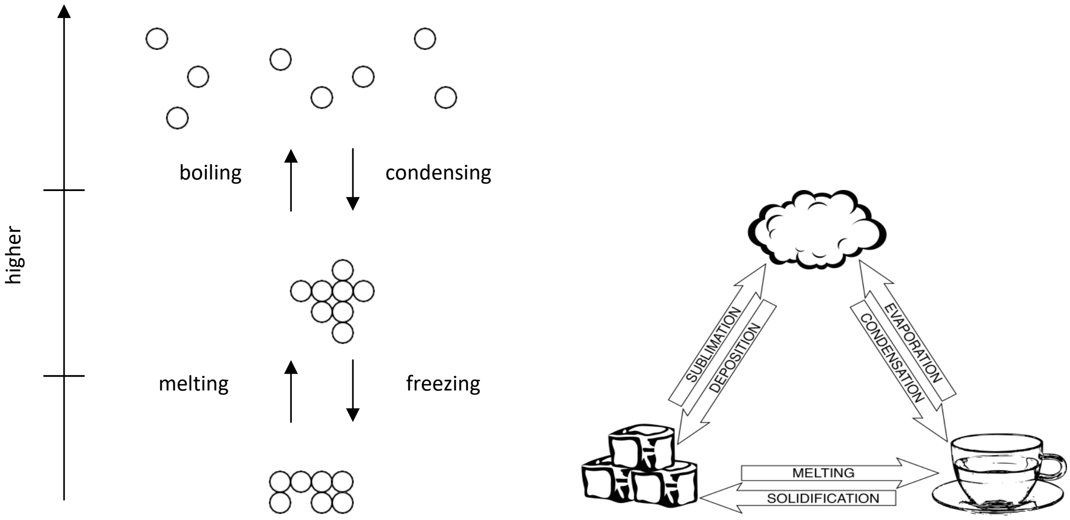
were able to use the knowledge they gained during POGIL lessons to answer item 8 and 9.

Below are some questions from POGIL worksheet 3, which might have helped students to answer item 8 and 9.

> *Why do particles in a solid eventually break away from their fixed positions when the solid is heated?*
>
> *What do the particles do as a liquid evaporates?*
>
> *The temperature at which a liquid turns to gas is known as its_*

However, for item 10, the control group scored better than the experimental group. Item 10 was about the changes of states of matter.

The experimental group completed a POGIL worksheet, "Changes of states of matter" (Activity 3) which covered the same concept. Interpretation of diagrams requires high cognitive skills (Lowe, 1996) and sometimes students experience difficulties with the interpretation of diagrams, which may have a negative impact on their learning of science (Schönborn et al., 2002). As shown in Figure 5.1, the diagram representing



PTDI Item 10 diagram

POGIL worksheet 3 diagram

Figure 5.1: States of matter diagram comparison in PTDI and POGIL worksheet

model 1 in the POGIL worksheet 3 was at the observational (macroscopic) level and the one in the PTDI diagnostic test was at the particle (sub-microscopic) level and this may have confused the students in the experimental group.

Table 5.8: Comparison of mean scores for second conceptual understanding for PTDI for Year 8 experimental (n = 24) and control group (n = 23)

Item No.	Description	Experimental	Control
1	Smoke particles move in random zigzag manner due to continuous collisions with air molecules	1.54	0.83
2	A gas diffuses more rapidly in partial vacuum due to much fewer collisions with air particles	1.25	1.65
6	Diffusion of a coloured substance is slow in water due to constant collisions with water molecules	1.04	1.00
7	An inflated balloon gradually decreases in size as air particles diffuse out through the pores in the balloon skin	1.42	1.30
Total		5.25	4.78

As shown in Table 5.8, the second conceptual category (diffusion in liquid and gases) consists of items 1, 2, 6 and 7. The combined tier score for the experimental group was high compared to the control group for items 1, 6 and 7. Only for item 2, the combined tier score for the experimental group was less than the control group. For CC2, the total mean for the experimental group was higher than the control group.

Item 1, 6 and 7 were about diffusion in liquids and gases and some of the questions in the POGIL worksheets as presented below definitely guided students in the experimental group.

> *Think about party balloons. What is inside the balloons?*
>
> *What happens to the party balloons after a day?*
>
> *Did the size of the balloon increase or decrease?*
>
> *Get some hot water and some cold water in two beakers and put a drop of coloured dye into each beaker. Observe what happens?*
>
> *Out of soap bar smell, scent bottle smell and coloured dye, which spreads further? Put them in order of most to the least?*

Overall, in all three categories, the experimental group scored higher than the control group. The PTDI data was analysed using the criteria presented in Table 3.8 in Chapter 3, which is same as used by Coştu et al. (2007). The Wilcoxon signed rank test was used to analyse the differences in PTDI test scores of experimental and control group students as presented in Table 5.9.

Table 5.9: Wilcoxon test results comparing PTDI for Year 8 experimental (n = 24) and control group (n = 23)

Group	Median	IQR	W	p	δ
Experimental	14	4.5	172	0.03	0.38
Control	12	5			

A Wilcoxon test indicated that the PTDI test scores were greater for the experimental group. The median for the experimental group was 14 (IQR = 4.5) whereas the median for the control group was 12 (IQR = 5). The test showed that the difference was statistically significant ($p < 0.05$). The effect size was also calculated to understand the influence of POGIL on students' understanding of particle theory of matter. Based on the guidelines for interpreting Cliff's delta as presented in Table 3.5 in Chapter 3, $\delta = 0.38$ signifies a medium effect size meaning that the effect is meaningful both statistically and practically. These findings proved that POGIL intervention helped students to improve their conceptual understanding for particle theory of matter.

5.5 Perceived curriculum

This section is about the perceived curriculum and answers research question 4 which is, "What are students' perceptions about the POGIL lessons?" The evaluation of the students' perceptions about POGIL was based on surveys, semi-structured interviews, teacher's observation and student reflection sheets.

5.5.1 Quantitative data

To ascertain the impact of POGIL on students' attitudes towards learning chemical science, quantitative data was collected using the Science Laboratory Environment Inventory (SLEI) and Attitude towards the Subject of Chemistry Inventory, version 2 (ASCIv2) questionnaire.

5.5.1.1 Science Laboratory Environment Inventory

In both the 2013 and 2014 studies, students were administered a Science Laboratory Environment Inventory (SLEI) questionnaire (Fraser et al., 1993) to collect some quantitative data on environmental contributions to learning. The SLEI has five scales each containing seven items with five responses where 1 is "Almost Never" and 5 is "Very Often". The data thus collected was statistically analysed using SPSS (IBM Corp, 2019) software to investigate the effect of POGIL on students' perceptions. As presented in Table 5.10 for the experimental group, the pre-test mean-scores of different scales for

SLEI ranged from 2.72 for Integration to 3.66 for the Rule Clarity and the post-test mean scores ranged from 2.69 for Integration to 3.54 for Rule Clarity.

A mixed-model ANOVA was used for statistical analysis with pre- and post-test as repeated measures, experimental and control group as between subject factor and year as covariate. After adjusting for differences in years, there was a significant main effect of POGIL pedagogy for Student Cohesiveness on the experimental group $F(1,97) = 18.53, p < 0.05, \eta_p^2 = 0.16$. For Open-Endedness $F(1,97) = 3.24, p = 0.08, \eta_p^2 = 0.03$, the result lacks significance at 5% however; it was significant at 10% level of significance. The Integration scale was found to be non-significant with $F(1,97) = 0.10, p = 0.75, \eta_p^2 = 0.00$. The Rule Clarity scale was found to be statistically significantly higher for the control group in comparison to the experimental group with $F(1,97) = 5.36, p = 0.02, \eta_p^2 = 0.05$. Lastly, for Material Environment there was non-significant main effect of POGIL on the experimental group $F(1,97) = 0.01, p = 0.91, \eta_p^2 = 0.00$. The mixed ANOVA result of scales for the experimental group indicate that out of the five scales of the SLEI, only two scales, i.e. Student Cohesiveness with a large effect size and Rule Clarity with a small effect size, was statistically significant. The result of the remaining three scales, Integration, Material Environment and Open-Endedness were not statistically significant.

The increase in the mean score for Student Cohesiveness for the intervention implies that students perceive a relatively high level of cohesiveness in their POGIL lessons. This is likely to be the case because in POGIL sessions students work together in small groups to achieve a common goal. These results are consistent with a study conducted in a Korean high school (Lee & Fraser, 2001). The low level of Open-Endedness observed in the POGIL classes was not statistically significant between groups, findings consistent with prior studies (Dunn, 2005; Fraser & Lee, 2009; Fraser & McRobbie, 1995). POGIL lessons provide students an opportunity to develop important cognitive and affective process skills, including problem solving, critical thinking and communication.

Disappointingly, the Material Environment and Integration were perceived nega-

Table 5.10: Descriptive statistics for Year 8 SLEI for 2013 (n = 48) and 2014 (n = 52)

Scale name	Group	Time	2013		95% CI		2014		95% CI	
			M	SD	LB	UB	M	SD	LB	UB
Student Cohesiveness	Experimental	Pre	3.08	0.50	2.88	3.28	3.27	0.76	2.98	3.55
		Post	3.46	0.44	3.28	3.64	3.43	0.64	3.19	3.68
	Control	Pre	3.51	0.39	3.34	3.69	3.51	0.40	3.34	3.68
		Post	3.03	0.37	2.86	3.19	3.27	0.45	3.07	3.46
Open-Endedness	Experimental	Pre	2.93	0.36	2.79	3.08	2.76	0.31	2.65	2.88
		Post	2.98	0.38	2.83	3.14	3.05	0.36	2.91	3.19
	Control	Pre	3.19	0.59	2.93	3.46	3.17	0.51	2.95	3.39
		Post	3.06	0.24	2.95	3.17	3.23	0.45	3.03	3.42
Integration	Experimental	Pre	2.72	0.33	2.59	2.85	2.76	0.32	2.63	2.88
		Post	2.78	0.57	2.55	3.01	2.69	0.52	2.49	2.89
	Control	Pre	2.82	0.46	2.62	3.02	2.76	0.41	2.59	2.94
		Post	2.69	0.31	2.55	2.83	2.80	0.30	2.67	2.93
Rule Clarity	Experimental	Pre	3.64	0.50	3.44	3.84	3.66	0.49	3.47	3.84
		Post	3.54	0.53	3.32	3.76	3.53	0.58	3.31	3.75
	Control	Pre	3.42	0.53	3.19	3.66	3.40	0.50	3.19	3.62
		Post	3.54	0.33	3.39	3.69	3.70	0.48	3.50	3.92
Material Environment	Experimental	Pre	3.56	0.40	3.00	3.32	3.14	0.40	2.98	3.29
		Post	3.40	0.41	3.23	3.56	3.27	0.36	3.13	3.40
	Control	Pre	2.56	0.48	2.34	2.77	2.55	0.27	2.44	2.67
		Post	2.79	0.40	2.60	2.97	2.72	0.39	2.55	2.88

*$p < .05$ significant scales are presented in bold

tively in both the experimental and the control group. The Rule Clarity was perceived to be inadequate with a drop in results for both groups however; the drop was statistically significant for the control group. This is likely because students rely too much on the teachers' explanations rather than trying to find the answers themselves, or maybe it was a new learning experience for the students and repeated experiences of a POGIL class might improve these aspects.

5.5.1.2 Attitude towards the Subject of Chemistry Inventory, version 2

The second survey that was used to collect some more qualitative data was a revised version of the Attitude towards the Subject of Chemistry Inventory, version 2 (ASCIv2) survey (Bauer, 2008; Xu & Lewis, 2011). This survey has eight items based on two scales — intellectual accessibility and emotional satisfaction. The instrument uses a 7-point semantic differential scale. The negatively stated items (1, 4, 5 and 7) were recoded and SPSS (IBM Corp, 2019) was used for descriptive analysis.

A mixed-model ANOVA was fitted with pre- and post-test as repeated measures, while group (experimental/control) was set as between subject factor and year as covariate. For both years, the mean scores for pre- and post-test ASCIv2 of both groups were compared as presented in Table 5.11.

The item means ranged from 3.32 to 4.63. A score of 4 on the scale indicates a neutral attitude towards chemistry. In both 2013 and 2014, the experimental group's mean score for Intellectual Accessibility has increased whereas for the control group it has decreased. Similarly, in both years the experimental groups mean score for Emotional Satisfaction also has increased. The control group mean score for Emotional Satisfaction decreased in 2013 and increased in 2014.

After adjusting for differences in years, there was a significant main effect of POGIL pedagogy for Intellectual Accessibility on the experimental group $F(1, 97) = 15.76, p < 0.05$ with a large effect size $\eta_p^2 = 0.14$. These results are similar to previous studies (Brandriet et al., 2011; Vishnumolakala et al., 2017). There was a non-significant effect for Emotional Satisfaction $F(1, 97) = 0.56, p = 0.046$ and the calculated effect size

Table 5.11: Descriptive statistics for Year 8 ASCIv2 for 2013 (n = 48) and 2014 (n = 52)

Scale name	Group	Time	2013		95% CI		2014		95% CI	
			M	SD	LB	UB	M	SD	LB	UB
Intellectual Accessibility	Experimental	Pre-test	3.58	0.67	3.31	3.85	3.61	0.75	3.31	3.91
	Post-test	4.04	0.62	3.79	4.29	4.39	0.52	4.18	4.59	
	Control	Pre-test	3.70	0.71	3.40	4.01	4.22	0.67	3.93	4.51
	Post-test	3.78	0.93	3.37	4.20	3.93	0.73	3.62	4.25	
Emotional Satisfaction	Experimental	Pre-test	4.06	0.70	3.78	4.34	3.97	0.84	3.64	4.30
	Post-test	4.18	0.51	3.40	4.39	4.20	0.50	4.00	4.40	
	Control	Pre-test	3.50	0.61	3.23	3.77	4.42	0.70	4.12	4.73
	Post-test	3.32	0.74	2.99	3.64	4.63	0.76	4.30	4.96	

*p < .05 significant scales are presented in bold

η_p^2 is 0.01 which is considered “small” according to Lakens (2013). These results reflect those of Brandriet et al. (2011) who also found that no correlation existed between Intellectual Accessibility (achievement) and Emotional Satisfaction (attitude). Some Year 8 students may have misunderstood the terms in Attitude towards the Subject of Chemistry Inventory, version 2 (ASCIv2) items leading to errors (Brown et al., 2014).

5.5.2 Qualitative data

Two forms of qualitative data were collected for triangulation purposes throughout the intervention: a reflection sheet and semi-structured interviews from the experimental group.

5.5.2.1 Strengths, areas for Improvement, and Insights reflection

To collect some qualitative data regarding the students’ perceptions about POGIL, SII reflection sheets (Wasserman & Beyerlein, 2007) were given to the students at the end of the POGIL activities. The qualitative data from students’ responses were analysed using summative content analysis, one of the three types of content analysis methods (Hsieh & Shannon, 2005). Summative content analysis was used to determine the keywords or content followed by the interpretation of the underlying context. Coding was accomplished by analysing students’ responses and categorising among common themes notes by the researcher. After careful examination of the students’ responses, four categories were formed as presented in Table 5.12. The categories were: Improved Performance, Active Learning, Group Work and Student Satisfaction.

The students’ responses about POGIL were further analysed for sentiment and were categorised as positive or negative comments. The data was summarised under the four categories and the overall percentage difference of comments was obtained by comparing the percentage of positive and negative comments presented in Table 5.13.

Student Satisfaction scored 139 positive and 22 negative comments with a percentage difference of 73%. This was followed by Improved Performance with 75 positive and 19 negative comments with a percentage difference of 60%. Active Learning

Table 5.12: Four categories that emerged out of the coding of Year 8 students SII qualitative data

Categories	Themes	Participants' responses
Improved Performance	Understanding of concepts, new concepts / key ideas	• I learnt about different states of matter. • Working in a group helped me to understand questions I did not know. • It did not help me much as people were copying my answers. • Now I understand the concept better.
Active Learning	Focussed, engaged, involvement	• We were focussed through the activity. • Some members were talking. • Our group needs to focus more. • We were doing more talking about the concept. • Everyone working on the same question.
Group Work	Helping each other, shared opinions	• Working as a group makes it easier to understand. • Sometimes questions were hard but other people helped me. • Everyone shared their opinions. • We got along very well as a group. • Group work can be challenging. • People in my group were not helping each other.
Student Satisfaction	Fun, arguments, enthusiasm, task accomplishment	• We got through the task quicker. • We helped each other. • We need to do less talking and more work. • More effort equals to more work done. • I enjoyed working with my friends. • It was fun to work with other people.

Table 5.13: Year 8 experimental group students SII reflection comment categories and sentiments

Category	Percentage		
	Positive	Negative	Difference
Improved Performance	75	19	59.6
Active Learning	63	26	41.6
Group Work	79	40	32.8
Student Satisfaction	139	22	73.0
Total	356	107	

scored 63 positive and 26 negative comments with a percentage difference of 42%. It was closely followed by Group Work with 79 positive and 40 negative comments and a percentage difference of 39%.

Overall, the results from Table 5.13 show that all the four categories had a positive gain. The majority of students had a positive response, which strongly supports the fact that students do like POGIL as compared to the teacher-centred method. This is confirmed clearly by the difference in the percentage for the overall negative comments (23%) and positive comments (77%).

5.5.2.2 Semi-structured interviews

At the end of the POGIL intervention, an experienced teacher conducted semi-structured interviews with five randomly selected students from the experimental group to explore their views about POGIL (Fontana & Frey, 2005). The interview questions were categorised in three sections. The first section consisted of four questions focussed on the group work (collaborative learning). The second section of the interview focussed on the POGIL worksheets. The third and last section of the interview looked at general questions about POGIL. Similar to SII reflection sheets, student responses were analysed to draw common themes to form four categories as presented in Table 5.14. A copy of the interview protocol is present in Appendix D. The interview data will be integrated with the discussion in the next section of this chapter.

Table 5.14: Four categories that emerged out of the coding of Year 8 students semi-structured interview qualitative data

Categories	Themes	Participants' responses
Process skills	critical thinking, problem solving communication, teamwork	• The critical thinking questions helped me think more deeply. • We discussed the answers and were able to solve the hard questions. • I helped my group with the answers and they helped me with some answers.
Resources	Pictures,key questions	• Pictures and diagrams are helpful in the worksheet as they are easy to understand. • The key questions in the worksheets help you to check your understanding about the topic. • Pictures help you visualise the thing and give you hints.
Collaborative learning	Helping each other, sharing	• My friends helped me put that information in sentences as I was struggling. • I was able to sit next to my friends and we helped each other.
Student Satisfaction	Fun, arguments, better method	• It was fun as we were allowed to talk and discuss things. • It is better than the teacher-centred method as we get to discuss the answers. • When I was not with my friends, we had too many arguments.

5.6 Discussion

This section presents the results and findings in response to research question 4. In seeking to investigate students' perceptions about POGIL activities in this study, it is useful to look at both the quantitative and qualitative data. The students were given random sequential numbers such as 8Sc_4, which represents a Year 8 science student number 4. Emerging from an analysis of student responses to the semi-structured interviews, the SII reflection sheets as well as teachers' observations, some trends were recognised. This integrates all sources of qualitative data into a single narrative to discuss these findings.

5.6.1 Collaborative learning

A majority of the students (4/5) responded positively for group work saying that it helped them to increase their conceptual understanding as it provided them the social and academic support. These views reflect those of Ghaith (2002). For example, student 8Sc_4 stated,

> *Group activities make it easier to apply the knowledge as you can discuss and come to conclusions. My understanding has definitely increased as my group members helped me with some answers. (8Sc_4)*

Speaking on the group work dynamics, 8Sc_3 and 8Sc_5 stated conceptual gains are made when group members help each other.

> *I really enjoyed collaborative learning. It was fun as we were allowed to talk and discuss things. I helped my group with the answers and they helped me with some answers. (8Sc_3)*

> *I enjoyed working in groups. I was able to sit next to my friends and we helped each other. It has helped me understand the topic better. (8Sc_5)*

In addition, an EAL student considered that collaborative learning is valuable as it gave them chance to interact with others and get help, as illustrated by the following quote.

> *It was good. We discussed the answers and were able to solve the hard questions. My friends actually helped me put the information in sentences as I was struggling. (8Sc_2)*

The following students' excerpts from SII reflection sheets indicate a positive view about POGIL and validates how students value the importance of group work in POGIL interactions:

> *Working in groups makes it easier to understand, we helped each other, we shared opinions, answering hard questions was easier, helped me understand concepts very well. I am not good in science so it helped me. People, who do not usually work, worked well, by discussing questions together, having more discussions, and learning this way is better and enjoyable. (Collective SII reflection comments)*

Additionally, the teacher observed students during the second POGIL session and took some notes as shown in Section 4.7.2 of Chapter 4. The notes also highlight the benefits of collaborative learning. Here are some group observations.

> *Everyone in the group is participating. Students are working at a good pace. They are discussing the answer together and are then writing in their worksheet. (Group 4)*

> *One student asks for help as he is struggling to write. Another student helps the other student to put the information in a proper sentence. Another student is asking for help to understand the meaning of a word. (Group 5)*

The results from SLEI also support a high level of Student Cohesiveness during POGIL lessons and highlights the importance of group assisted learning in understanding concepts. This is evident from the significant difference in achievement of the experimental group students in the end topic test, 2013 diagnostic test and PTDI test.

Significant differences in Intellectual Accessibility from ASCIv2 data also provide further evidence that many students perceive chemistry as easy, simple and clear when they work collaboratively. It can be established that POGIL is a feasible way to present the information and students find it beneficial.

Students found some problems in the worksheets challenging but indicated that with the help of their peers they managed to solve them. Along with the assertion of learning found by the diagnostic and end topic tests, SII reflection data show that about 32.8% students responded positively to group work and 60% students indicated an increase in their conceptual understanding. These findings suggest that students understand concepts better when they participate actively in small group discussions (Vishnumolakala, 2013) that can effectively improve their learning outcomes (Haryati, 2018).

5.6.2 Resources

Another theme to emerge from these comments is about the resources. Students regarded POGIL worksheets highly valuable such as this view shared by student 8Sc_3.

> *I like pictures, as they are attractive and not boring. They help you visualise the thing and give you hints. The key questions are good as they force you to think about it and apply the knowledge. (8Sc_3)*

Similarly, students 8Sc_4 and 8Sc_5 stressed the importance of key questions in the POGIL worksheets by saying,

> *The key questions in the worksheets help you to check your understanding about the topic. (8Sc_4 and 8Sc_5)*

Students 8Sc_1 and 8Sc_2 felt that pictures and diagrams in the POGIL worksheets helped them understand and answer the questions.

> *Yes, the pictures are helpful as they provided us with clues and information to answer the questions. I wish they were in colour, which is clearer. (8Sc_1)*

Pictures and diagrams are helpful in the worksheet as they are easy to understand. They provide you the information to answer the questions. The critical thinking questions helped me think more deeply and my friends helped me put that information in sentences. (8Sc_2)

From the above analysis, it can be seen that students acknowledge the benefits of POGIL worksheets as they guide them through an exploration to construct, expand, improve or integrate their conceptual understanding (Toyo et al., 2019). These findings are in accordance with the opinion shared by Vishnumolakala (2013). However, there were no significant differences in the Material Environment findings in the SLEI survey. This could be due to a lack of adaptation of instrument in the intended audiences. This is a limitation for this study and will be further discussed in Chapter 7.

5.6.3 Process skills

Students also mentioned they learned some process skills such as critical thinking, problem solving and information processing in addition to skills like communication, teamwork, leadership and collaboration (Hanson, 2013; Kussmaul, 2016). Student 8Sc_3 felt that group discussions help improve communication skills and highlights its importance by saying,

I really enjoyed collaborative learning. It was fun as we were allowed to talk and discuss things. I helped my group with the answers and they helped me with some answers. (8Sc_3)

Student 8Sc_2 considered the importance of critical thinking ability. The following excerpt supports the view:

The critical thinking questions helped me think more deeply and my friends helped me put that information in sentences. (8Sc_2)

The teacher also made some observations during POGIL sessions which highlight students' leadership skills and communication skills.

Students are focussed on the worksheet. Reader is reading out the questions. One student is directed to focus back on the worksheet by the manager. (Group 1)

Students are discussing Q4. One student directs them to read information from model 2. Everyone is listening while student goes through the points in the model 2. (Group 2)

As discussed in Chapter 4 Section 4.7, 60% of students considered that their collaborative learning skills have increased significantly during POGIL activities. This data further supports that during POGIL lessons in addition to conceptual gains, students also reported an increase in their process skills. POGIL activities use a Karplus learning cycle model based on exploration, concept development and application and provides an appropriate environment to address these process skills (Murphy et al., 2010; Pizzi, 2014). These findings are consistent with previous research that has also demonstrated an improvement in students critical thinking and problem-solving skills (Soltis et al., 2015).

5.6.4 Satisfaction

Every student who was interviewed considered that POGIL activities are more beneficial than traditional teaching where they listen to the teacher and use a textbook to do the worksheets individually. They expressed the view that since these activities involve active group discussions, the approach keeps them focussed. For example, students 8Sc_4 and 8Sc_5 stated,

This method keeps you engaged and focussed, as it is more interactive as compared to the teacher-centred method where we just sit and listen. (8Sc_4)

It is better than the teacher-centred method as we get to discuss the answers. We participated actively and it is not boring. (8Sc_5)

Similarly, students described how they were actively engaged during the POGIL activities.

It's better than the teacher-centred method because we are more active in this method. (8Sc_2)

It is definitely better than teacher-centred method because we are not just sitting there and listening. We actually have to do activities and discuss things. (8Sc_3)

The views expressed above are further validated by SII reflection data in which about 73% students conveyed their satisfaction with the POGIL activities. However, a few students expressed their dissatisfaction with POGIL as mentioned by student 8Sc_1,

When I was not with my friends, we had too many arguments. My understanding has stayed the same because mostly in my group students were copying answers from me. (8Sc_1)

During the second POGIL session, the teacher took some observations and noticed a lack of interest and engagement among group 3 and group 6 students.

This group has more members than the other groups. There is no discussion happening and students are doing their own work. Students are a bit slow to follow through the worksheet. Some students asked if they could change the group. (Group 3)

Two students are talking about something else and not doing their work. The rest of the group is doing their work but there is not much discussion happening. (Group 6)

Further, to improve POGIL learning some suggestions were made by 8Sc_1.

Do not put some people together in the same group as they talk too much.

This point is reflected in SII student reflection data for group work (33%) which shows a weaker difference compared to other categories. Similarly, insignificant Emotional Satisfaction results for ASCIv2 indicate that students consider that chemistry is frustrating, uncomfortable and complicated as they fail to understand the language of chemistry (Cardellini, 2012). These findings are in accordance with another study by Brandriet et al. (2011). Only a few students preferred a teacher-centred method mainly due to poor collaboration among some group members as mentioned in their responses. This may result from the problem of social loafing in collaborative learning (Aggarwal & O'Brien, 2008; Chang & Brickman, 2018). The students at this year level were not always positive about working in group and these findings are in line with previous studies which highlight the problems associated with cooperative learning (Wilhelm, 2007).

In order for cooperative learning groups to function effectively, a teacher must establish a clear set of expectations that are to be followed by every member of the group (Slavin, 1991) and students must develop trust to solve conflicts cordially (Johnson & Johnson, 2009). While an attempt was made by the researcher to assign students to appropriate groups, it seems the duration of engagement was not long enough for effective teamwork to develop among this early adolescent group of students.

These findings suggest that, in general, a majority of the students clearly agreed that the POGIL method is more engaging and interactive compared to the traditional teacher-centred method. Students' perceived that they made process and conceptual gains by working in small groups as the design of POGIL activities guided students through an exploration of a model that contains some new information (Bénéteau et al., 2017). These outcomes are broadly in harmony with those of researchers such as Barthlow (2011) and Qureshi et al. (2017). They also reported a strong positive correlation between the active learning and the process skills (Vishnumolakala, 2013). These conclusions will contribute to research question 4 and will be discussed alongside the other related findings in Chapter 7.

5.7 Summary

The third research question (RQ3) used quantitative measures to investigate if there is any difference in the students' achievement in selected diagnostic tests and school-based tests in chemistry after using POGIL in comparison to teacher-centred learning style. The mean score of the multiple-choice questions diagnostic test and end of topic test had shown an increase in students' achievement in chemistry when taught using the POGIL pedagogy compared to the teacher-centred learning method. The PTDI two-tier diagnostic test revealed that in all the three conceptual categories the experimental group performed better than the control group. These findings are consistent with previous research that has also demonstrated an upwards trend in students' conceptual understanding following POGIL intervention (Qureshi et al., 2017; Walker & Warfa, 2017).

The fourth research question (RQ4) used qualitative and quantitative methods to investigate the students' perceptions about the POGIL pedagogy. The quantitative data was collected by SLEI and ASCIv2. The mean scores of the SLEI and ASCIv2 items indicated that experimental group students perceived POGIL lessons favourable compared to the control group. The qualitative analysis of the semi-structured student interviews and their responses to SII reflection sheet indicated the positive impact on conceptual understanding when they actively contributed in small group discussions in a POGIL class. Further, the experimental group students reported the development of process skills because of their active small group interactions.

Chapter 6

POGIL in Year 11 Classes — Achieved and Perceived Curriculum

6.1 Introduction

The chapter examines the third and fourth research questions in the context of the Year 11 study, using a single group pre-experimental design. The chapter begins with information about the data collection journey of the Year 11 chemistry class (Section 6.2). To answer the third research question (RQ3), “Are there any difference in students’ achievement in selected diagnostic tests and school-based tests in chemistry after the teaching intervention?” (Section 6.3), two diagnostic tests are used. The fourth research question (RQ4), “What are students’ perceptions about the POGIL method?” (Section 6.4) is addressed by considering students’ responses to the learning environment and attitude towards chemistry instruments. The chapter concludes with a summary of the data analysis pertaining to the achieved and perceived curriculum for the Year 11 study group (Section 6.5) and a conclusion of the chapter (Section 6.6).

6.2 Year 11 Chemistry class data collection journey

The Year 11 study was conducted at the researcher’s school in 2013 as a complimentary study to the Year 8 study (see Chapter 5). This is due to the fact that Year 11 students being in an upper secondary class have more developed social skills, thus giving the researcher an opportunity to compare with Year 8 students who have less developed social skills. This study with two of the researcher’s Year 11 chemistry classes (upper secondary school) is much closer to the POGIL studies conducted at the tertiary level, so some similarities may be evident. The students were given a pre- and a post-test on acids and bases (the Acid and Bases Concept Inventory – ABCI) to assess their improvement. The pre-test was administered to the students before the treatment, which was at the same time the College and University Classroom Environment Inventory (CUCEI) questionnaire (Fraser et al., 1986) and a revised version of Attitude towards the Subject of Chemistry Inventory, version 2 (ASCIv2) survey (Xu & Lewis, 2011) were administered. The CUCEI questionnaire was given to collect some quantitative data on environmental contributions to learning. For the next five weeks, five POGIL based activities were used for the study. After the treatment, the students finished the CUCEI questionnaire, the ASCIv2 attitude survey and the post-test on acids and bases.

In 2014, the researcher did not teach a Year 11 chemistry class so after a gap of one year, the 2013 study was repeated in 2015 but this time the Acid-Base Reactions Concept Inventory (ABCI) was used (Jensen, 2013) as a pre- and post diagnostic test. Again, as per the previous study, the students were administered the ABCI, CUCEI and ASCIv2 surveys during the first week. Over the next few weeks they studied the topic "Acids and Bases" using POGIL activities. This time students were given SII reflection sheets at the end of POGIL activities to collect some qualitative data. After the treatment, they repeated the ABCI, CUCEI and ASCIv2 surveys again. In addition to this, an experienced chemistry teacher also interviewed some randomly selected students to collect in-depth data for triangulation purposes. The interview protocol and SII reflection can be found in Appendix D.

6.3 Achieved curriculum

The achieved curriculum defines students' conceptual understanding and can be measured by means of a range of assessments (Amaral & Garrison, 2007). For this study, the evaluation of the effect of POGIL pedagogy on students' achievement was based on two assessments, namely a multiple-choice questions test on acids and bases and a two-tier Acid-Base Reactions Concept Inventory (ABCI). The present section provides further evidence to assist in answering research question 3, “Are there any differences in students’ achievement in selected diagnostic tests and school-based tests in chemistry after the teaching intervention?”

6.3.1 Acid-Base diagnostic test

The first assessment was a teacher-made multiple-choice questions test on acids and bases, which was used in 2013 study and scored out of 25 (Appendix C). The results of the test, presented in Table 6.1, show that the students’ mean score increased from 13.69 in the pre-test to 16.19 in the post-test.

Table 6.1: Descriptive statistics for acid-base 2013 diagnostic test for Year 11 group (n = 16)

Time	M	SD	95% CI	
			LB	UB
Pre-test	13.69	3.52	11.81	15.66
Post-test	16.19	3.58	14.28	18.10

A paired-sample two-tailed t-test was conducted to compare the results of the pre-test and post-test. The test indicated that students’ post-test scores ($M = 16.19, SD = 3.58$) were statistically significantly higher than their pre-test scores ($M = 13.69, SD = 3.52$), $t(15) = 3.42, p < 0.05$. The mean increase in the test scores was 2.50 with a 95% confidence interval. The effect size for the paired samples t-test was also computed to understand the impact of POGIL activities.

According to the guidelines for interpreting the Cohen’s d values as presented in Table 3.5 in Chapter 3, a value of 0.71 which indicates a medium effect size, means that it is very unlikely that students’ post-test scores were higher than the pre-test score due to statistical chance and that effect of the POGIL intervention is meaningful both statistically and practically. These results suggest that students’ understanding of the concepts of acid-base reactions had significantly improved after using the POGIL pedagogy.

6.3.2 Acid-Base Reactions Concept Inventory

To measure students' conceptual gains, in the 2015 study, researcher decided to use a more robust diagnostic tool like the ABCI, which has been previously tested and validated (Jensen, 2013). The ABCI consisted of 11 two-tier questions and is presented in Appendix C. The first tier in each item asks students to identify whether a particular reaction is as acid-base reaction. The second tier asks students to provide a reason for their choice. The ABCI data were analysed using the criteria that Coştu et al. (2007) presented in Table 3.8 in Chapter 3. The difference between the pre- and post-test scores were examined for statistical significance using the Wilcoxon test as presented in Table 6.2.

Table 6.2: Wilcoxon test results comparing ABCI results for Year 11 group (n = 16)

Pre		Post		W	p	δ
Median	IQR	Median	IQR			
10	3.5	15	6.25	3.5	0.00	0.58

The Wilcoxon test indicated that there were statistically significant differences between pre- and post-test scores ($p < 0.05$). The median for the post-test was 15 ($IQR = 6.25$) whereas the median for the pre-test was 10 ($IQR = 3.5$). The effect size was also computed to understand the effect of POGIL on students' understanding of acid-base reactions. According to the guidelines for interpreting Cliff's delta, as presented in Table 3.5 in Chapter 3, $\delta = 0.58$ indicated a large effect size which is meaningful both statistically and practically. Thus, we can conclude that there was a high degree of certainty and the observed effect was not due to chance indicating that after POGIL intervention, students' understanding of acid-base concept has increased.

The overall percentage of students in the pre-test and post-test ABCI was obtained by comparing the percentage of students who scored both tiers correctly in each item two-tier item with the percentage who scored only the first-tier correctly as presented in Table 6.3.

The percentage of students who correctly answered the first tier of multiple-choice

Table 6.3: Percentage of Year 11 students who correctly answered the first tier and both tiers of the ABCI items

Item	% of correct responses			
	Pre-test		Post-test	
	First tier	Both tiers	First tier	Both tiers
1	56	38	63	44
2	6	6	25	25
3	31	25	50	6
4	63	0	38	31
5	75	0	81	13
6	56	6	75	31
7	81	25	88	38
8	19	6	69	25
9	13	13	94	69
10	81	50	82	38
11	63	0	50	6

items ranged from 6% to 81% in the pre-test as compared to 25% to 88% in the post-test. The percentage of students who correctly answered the both parts of the two-tier items ranged from 0% to 50% in the pre-test as compared to 6% to 69% in the post-test. Nine out of 11 items indicated an increase in ABCI scores in the post-test. This trend indicates that after POGIL intervention students' understanding of acid-base reactions concept has increased.

There is a huge amount of content to cover in Year 11 chemistry syllabus. The POGIL activities were chosen to cover topics other than just the acid-base reactions. Analysis of the link of four ABCI items 9, 4, 10 and 3 to the POGIL worksheets are discussed below showing that there was a significant change after the POGIL intervention.

Item 9

In this item, students were asked to classify the reaction shown in Figure 6.1 as acid-base reaction.

Is this an acid-base reaction?

$$HCN\ (aq) + H_2O\ (aq) \longrightarrow H_3O^+\ (aq) + CN^-\ (aq)$$

Y) Yes N) No

I chose my answer to question 9 because ______________

A) water is neutral

B) there are no acids or bases in the reactants and products

C) H_2O is an acid because it accepts a proton to become H_3O^+ and HCN is a base because it donates a proton to become CN^-

D) H_2O is a base because it accepts a proton to become H_3O^+ and HCN is an acid because it donates a proton to become CN^-

Figure 6.1: Item 9 from the ABCI

As displayed in Table 6.4, item 9 has the highest learning gain as the percentage increased from 12.5% in the pre-test to 75% in the post-test. In the pre-test, 87.5% students chose their answer as "No" considering item 9 as not an acid-base reaction. This could be attributed to students' lack of awareness that HCN can act as an acid and H_2O can act as a base. This question required students to understand the Brønsted-Lowry theory and identify the conjugate acid-base pairs. Model 2 in the POGIL activity, "How do acids and bases behave in water?" enables students to interact amongst each other and further develop their skills and understanding as shown in Figure 6.2.

Table 6.4: Percentages of student response pattern to item 9 in the ABCI

Time	Answer	Reason				
		A	B	C	D	Total (%)
Pre-test	Yes	0(0)	0(0)	0(0)	2(12.5)*	12.5
	No	7(43.7)	6(37.5)	0(0)	1(6.3)	87.5
Post-test	Yes	1(6.3)	0(0)	2(12.5)	12(75)*	93.8
	No	0(0)	0(0)	1(6.3)	0(0)	6.3

Reaction 1	$HCl(g)$ (acid)	+ $H_2O(l)$ (base)	⇄	$H_3O^+(aq)$ + $Cl^-(aq)$
Reaction 2	$NH_3(aq)$ (base)	+ $HF(aq)$ (acid)	⇄	$NH_4^+(aq)$ + $F^-(aq)$
Reaction 3	$NH_4^+(aq)$ (acid)	+ $H_2O(l)$ (base)	⇄	$NH_3(aq)$ + $H_3O^+(aq)$
Reaction 4	$F^-(aq)$ (base)	+ $H_2PO_4^-(aq)$ (acid)	⇄	$HPO_4^{2-}(aq)$ + $HF(aq)$

Identify the Brønsted-Lowry acids in Model 2.

Figure 6.2: Model 2 adapted from Quinton et al. (2018) from POGIL worksheet "How do acids and bases behave in water?"

Item 4

In item 4, students were asked to classify the following reaction in Figure 6.3 as an acid-base reaction.

Is this an acid-base reaction?

$$HNO_3\,(aq) + NH_3\,(aq) \longrightarrow NH_4NO_3\,(aq)$$

Y) Yes N) No

I chose my answer to question 4 because ________________

A) HNO_3 bonds to NH_3 to form one product

B) there is only one product. There is no conjugate acid or conjugate base

C) a proton is donated and accepted

D) the product will dissociate into spectator ions

Figure 6.3: Item 4 from the ABCI

In the pre-test, for this item, 0% of the students gave a correct response and reason (Yes-C). A further 62.6% of the students have chosen a correct response (Yes) but an incorrect reason (A). In the post-test, a significant improvement (31.3%) in students' understanding about Brønsted-Lowry acid-base theory was evident from the data presented in Table 6.5. Students attempted similar questions in the POGIL worksheet as presented in Figure 6.2, which definitely helped students to understand this concept and apply the knowledge here. A significant number of the students (62.5%) still could not identify reaction as an acid-base reaction (No-A, No-B and No-D).

Table 6.5: Percentages of student response pattern to item 4 in the ABCI

Time	Answer	Reason				
		A	B	C	D	Total (%)
Pre-test	Yes	5(31.3)	3(18.8)	0(0)*	2(12.5)	62.6
	No	1(6.3)	4(25)	0(0)	1(6.3)	37.6
Post-test	Yes	1(6.3)	0(0)	5(31.3)*	0(0)	37.6
	No	2(12.5)	7(43.7)	0(0)	1(6.3)	62.5

Item 10

In this item, students were asked to classify the following reaction in Figure 6.4 as acid-base reaction.

Is this an acid-base reaction?

$$KOH\ (aq) \quad + \quad HNO_3\ (aq) \quad \longrightarrow \quad KNO_3\ (aq) \quad + \quad H_2O\ (aq)$$

Y) Yes N) No

I choose my answer to question 10 because HNO_3 and KOH ________________, and H^+ and OH^- ________________, and K^+ and $NO_3{}^-$ ________________.

A) ..... dissociate ..... combine to form ..... combine to form bonds.

B) .....dissociate ..... remain in solution as ions ..... remain in solution as ions

C) ..... dissociate ..... combine to form ..... remain in solution as ions

D) HNO_3 and KOH do not dissociate. They switch cations.

Figure 6.4: Item 10 from the ABCI

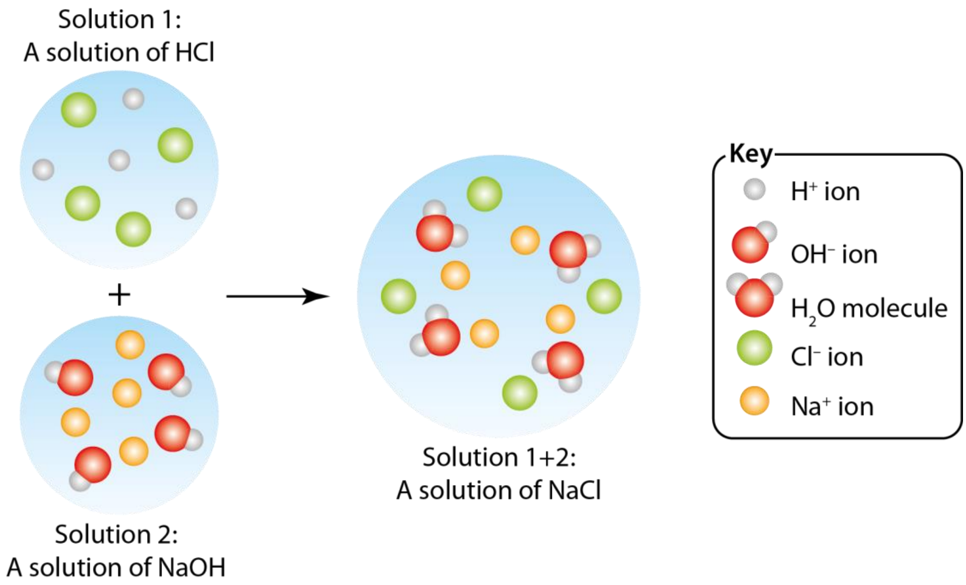
Surprisingly for item 10, the percentage of students who answered two-tier correctly decreased from 50% in the pre-test to 38% in the post-test. As presented in Table 6.6, only six students chose the correct response and reason, while 43.7% of the students chose (Yes-A) in the post-test indicating a misunderstanding that HNO_3 and KOH dissociate and H^+ and OH^- combine to form water, and K^+ and NO_3^- combine to form bonds.

Table 6.6: Percentages of student response pattern to item 10 in the ABCI

Time	Answer	Reason				
		A	B	C	D	Total (%)
Pre-test	Yes	4(25)	1(6.3)	8(50)*	0(0)	81
	No	1(6.3)	0(0)	2(12.5)	0(0)	19
Post-test	Yes	7(43.7)	0(0)	6(37.5)*	0(0)	81
	No	2(12.5)	0(0)	1(6.3)	0(0)	19

Students did look at a similar model in the POGIL worksheet "Reactions of acids and bases" (Appendix C) as presented in Figure 6.5, but perhaps due to the lack of understanding of the links between the different levels of chemistry, they could not apply this knowledge to item 10 in the post-test. One contributing reason for these low scores was that the teacher had little time to address the aqueous solutions concept in class, either by traditional methods or by use of POGIL instruction.

Model 1



Key Questions

a) Name the species present in aqueous solution of HCl in model 1 part (a).

---

b) Name the species present in aqueous solution of NaOH in model 1 part (b).

---

c) Name the species formed when HCl reacts with NaOH:

---

d) Name the species which do not take part in the reaction:

---

e) Write net ionic equation for the above reaction.

Figure 6.5: Model 1 adapted from Quinton et al. (2018) from POGIL worksheet "Reactions of acids and bases"

Item 3

In this item, students were asked to classify the following reaction in Figure 6.6 as acid-base reaction.

Is this an acid-base reaction?

$$Zn\ (aq) \quad + \quad 2\,HCl\ (aq) \quad \longrightarrow \quad ZnCl_2\ (aq) \quad + \quad H_2\ (aq)$$

Y) Yes N) No

I chose my answer to question 3 because ________

A) a proton is donated and accepted

B) in the reverse direction, H_2 can donate a proton to $ZnCl_2$

C) one electron is transferred to H^+

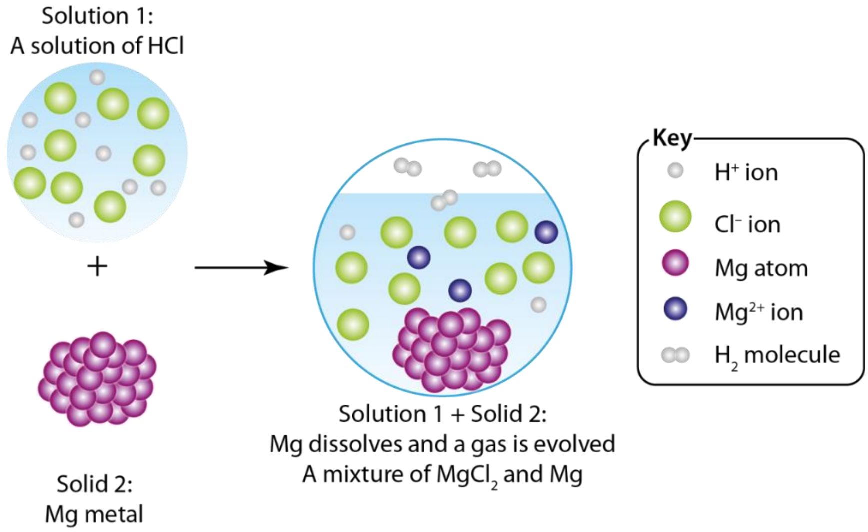
D) Cl^- donates an electron pair to Zn

Figure 6.6: Item 3 from the ABCI

As shown in Table 6.7, 18.8% students have correctly (No-C) answered item 3 in the pre-test. About 68.8% of the students chose either 'No-A' or 'No-B' as their answer. Compared to the post-test performance, a drop to 6.2% (No-C) indicated that a number of students hold the misunderstanding that a "proton is donated and accepted" (No-A) and "in the reverse direction, H_2 can donate proton to $ZnCl_2$" (No-B). The percentage of students who incorrectly considered item 3 as an acid-base reaction increased from 6.2% in the pre-test to 25% in the post-test.

While completing the "Reactions of acids and bases" POGIL worksheet (Appendix C) in Model 4, students looked at an example of reaction of acids with metals as presented in Figure 6.7. This was hypothesised as being mainly due to a lack of understanding of reactions other than acid-base, as this model might have confused students thinking that this is an acid-base reaction.

Model 4



Key Questions

a) What state of matter is Mg present in model 4 part (a).

---

b) Name the species present in aqueous solution of HCl in model 4 part (b).

---

c) Name the species formed when Mg reacts with HCl.

---

d) Name the species which do not take part in the reaction:

---

e) Write net ionic equation for the above reaction.

Figure 6.7: Model 4 adapted from Quinton et al. (2018) from POGIL worksheet "Reactions of acids and bases"

Table 6.7: Percentages of student response pattern to item 3 in the ABCI

Time	Answer	Reason				
		A	B	C	D	Total (%)
Pre-test	Yes	0(0)	0(0)	0(0)	1(6.2)	6.2
	No	6(37.5)	5(31.3)	3(18.8)*	1(6.2)	93.8
Post-test	Yes	0(0)	0(0)	0(0)	4(25)	25
	No	8(50)	3(18.8)	1(6.2)*	0(0)	75

Overall, for all the items except items 3 and 10, the percentage of students who correctly answered the two-tier items increased from pre-test to post-test. This trend indicates that after the POGIL intervention, students' understanding of acid-base concept has increased. In Model 1 and 4, coloured particles were used in the pictures which might have resulted in some alternative conceptions. This is a potential limitation and will be discussed further in Chapter 7. However, the potential for these alternative conceptions is very low as the worksheet was used in a guided inquiry setting where pictorial, symbolic and other forms of representations were provided to the students. This section has discussed data pertaining to the achieved curriculum. The next section will look at the data relating to perceived curriculum.

6.4 Perceived curriculum

This section focuses on the research question 4, "What are students' perceptions about the POGIL lessons?" Students' perceptions about POGIL were analysed using surveys, semi-structured interviews, teacher's observations and student reflection sheets.

6.4.1 Quantitative data

Quantitative data was collected using College and University Classroom Environment Inventory (CUCEI) and Attitude towards the Subject of Chemistry Inventory, version 2 (ASCIv2) questionnaire to ascertain the impact of POGIL on students' attitude towards learning Chemistry.

6.4.1.1 College and University Classroom Environment Inventory

In both the 2013 and 2015 Year 11 studies, students were administered College and University Classroom Environment Inventory (CUCEI) questionnaire (Fraser et al., 1986) to collect some quantitative data regarding students' perception about POGIL. The instrument contains 49 statements, having seven statements for each scale. The respondent is offered a four-point scale where 1 is "Strongly Agree" and 5 is "Strongly Disagree".

From the results shown in Table 6.8, it can be seen that in 2013, the mean scores of the different scales of the CUCEI ranged from 1.93 for Involvement pre-test to 3.02 for Personalisation post-test whereas in 2015 the mean scores ranged from 1.97 for Student Cohesiveness pre-test to 2.67 for Satisfaction and Personalisation post-test. The mean scores for post-test were slightly higher than the pre-test except for Innovation where it decreased. This result highlights that students do recognise the importance of cooperative learning and they find POGIL lessons interesting and enjoyable. In both pre-test and post-test, the standard deviation values are less than 1.0, indicating there is low variance in the results.

A mixed-model ANOVA with repeated measures was used to analysis CUCEI results. After adjusting for differences in years, there was a statistically significant effect of POGIL for Involvement $F(1, 31) = 6.24, p < 0.05, \eta_p^2 = 0.17$ and for Satisfaction $F(1, 31) = 4.48, p < 0.05, \eta_p^2 = 0.13$. For the remaining four scales, the results were non-significant for Personalisation $F(1, 31) = 1.34, p = 0.26, \eta_p^2 = 0.41$, Student Cohesiveness $F(1, 31) = 0.02, p = 0.88, \eta_p^2 = 0.00$, Task Orientation $F(1, 31) = 0.95, p = 0.34, \eta_p^2 = 0.03$, Innovation $F(1, 31) = 0.07, p = 0.80, \eta_p^2 = 0.00$ and Individualisation $F(1, 31) = 0.04, p = 0.85, \eta_p^2 = 0.00$.

The mean scores for all scales of CUCEI increased except Innovation but only Involvement and Satisfaction were statistically significant by traditional standards. This result is similar to findings reported by Nair and Fisher (2001) and indicates an op-

Table 6.8: Year 11 chemistry descriptive statistics for CUCEI data

Scale name	Time	2013 (n = 16)				2015 (n = 17)			
		M	SD	95% CI		M	SD	95% CI	
				LB	UB			LB	UB
Personalisation	Pre	2.30	0.35	2.12	2.48	2.14	0.52	1.89	2.39
	Post	3.02	0.31	2.86	3.18	2.67	0.64	2.36	2.98
Involvement	Pre	1.93	0.22	1.81	2.04	2.14	0.54	1.88	2.40
	Post	2.75	0.42	2.53	2.98	2.51	0.63	2.20	2.82
Student Cohesiveness	Pre	2.19	0.27	2.04	2.33	1.97	0.64	1.66	2.28
	Post	2.90	0.28	2.75	3.05	2.61	0.64	2.31	2.92
Satisfaction	Pre	2.60	0.23	2.47	2.72	2.46	0.62	2.17	2.76
	Post	3.06	0.12	3.00	3.12	2.67	0.66	2.35	2.99
Task Orientation	Pre	2.35	0.33	2.17	2.52	2.19	0.56	1.92	2.46
	Post	2.50	0.31	2.33	2.66	2.45	0.58	2.17	2.73
Innovation	Pre	2.82	0.32	2.65	2.99	2.52	0.61	2.22	2.81
	Post	2.71	0.48	2.46	2.97	2.48	0.72	2.13	2.83
Individualisation	Pre	2.40	0.26	2.26	2.54	2.11	0.52	1.86	2.36
	Post	2.47	0.38	2.27	2.68	2.15	0.55	1.89	2.42

$^{*}p < .05$ significant scales are presented in bold

portunity for enhancement for Involvement and Satisfaction dimensions of the course. Students felt that POGIL provides them with the opportunity to express their opinions in the class and they find POGIL classes interesting and look forward to coming to these classes. These dimensions, which correspond to the degree to which students participate actively and attentively in class activities as well the amount of enjoyment of classes, are well aligned with the objectives of the POGIL classroom.

Surprisingly, the items that the researcher anticipated would change after the POGIL intervention as highlighted by the qualitative data discussed in Section 6.4.2, did not change. It is difficult to explain this result, but it might be related to the language of the CUCEI items. To understand the magnitude of the effect of POGIL on the post-test results, the effect sizes were also computed as described in Table 3.5 in Chapter 3. The partial eta squared value of more than 0.14 for Involvement and Satisfaction indicated a very large effect size confirming a high degree of confidence that the positive effect of POGIL on Involvement and Satisfaction is not due to chance and the effect is meaningful both statistically and practically.

6.4.1.2 Attitude towards the Subject of Chemistry Inventory, version 2

In both the 2013 and 2015 studies, the impact of POGIL on students' attitude toward chemistry was evaluated using the Attitude towards the Subject of Chemistry Inventory, version 2 (ASCIv2) survey. The negatively stated items (1, 4, 5 and 7) were recoded as explained in Chapter 3 and data was analysed using SPSS (IBM Corp, 2019) software. Descriptive statistics were performed using SPSS and pre- and post-test mean scores for both scales of ASCIv2 were compared. The mean score for both ASCIv2 scales increased in both 2013 and 2015 except for Emotional Satisfaction, which indicated a slight drop in 2013. From the results in Table 6.9, it can be seen that in 2013, the mean scores of the different scales of the ASCIv2 ranged from 3.33 for Intellectual Accessibility pre-test to 4.38 for Emotional Satisfaction post-test whereas in 2015, the mean scores ranged from 3.38 for Emotional Satisfaction pre-test to 4.06 for Intellectual Accessibility post-test.

Table 6.9: Year 11 chemistry descriptive analysis for ASCIv2 data

Scale name	Time	2013 (n = 16)				2015 (n = 17)			
		M	SD	95% CI		M	SD	95% CI	
				LB	UB			LB	UB
Intellectual Accessibility	Pre	3.33	1.18	2.70	3.96	3.62	0.95	3.16	4.08
	Post	3.64	0.96	3.13	4.15	4.06	1.03	3.56	4.56
Emotional Satisfaction	Pre	4.38	0.97	3.86	4.90	3.38	0.97	2.92	3.85
	Post	4.25	1.08	3.67	4.83	3.51	1.03	3.02	4.01

$^*p < .05$ significant scales are presented in bold

A mixed-model ANOVA with repeated measures was performed to evaluate the differences in the change of means over the course of time. After adjusting for differences in years, it was found that there was a statistically significant difference between pre- and post-test for Intellectual Accessibility $F(1, 31) = 6.11, p < 0.05, \eta_p^2 = 0.17$ which is comparable to a study done by Xu (2014). According to Table 3.5 in Chapter 3, Intellectual Accessibility indicated a very large effect size (0.17) ensuring that the observed effect is meaningful both statistically and practically and is not due to a chance.

For Emotional Satisfaction, $F(1, 31) = 1.99, p = 0.18, \eta_p^2 = 0.06$ suggest that the difference is not statistically significant which is consistent with a study conducted by Brandriet et al. (2011). The chemistry Year 11 group in both years had some English as Additional Language (EAL) students and they may have misunderstood the terms in ASCIv2 items leading to errors (Brown et al., 2014). The following sections discuss the results of the qualitative data.

6.4.2 Qualitative data

Similar to the Year 8 study, for triangulation purposes qualitative data was collected using Strengths, areas for Improvement, and Insights (SII) reflection sheets and students' semi-structured interviews.

6.4.2.1 Strengths, areas for Improvement, and Insights

In both 2013 and 2015, students in the Year 11 study were administered SII reflection sheets (Wasserman & Beyerlein, 2007) to collect some qualitative data regarding the students' perception about POGIL. A copy of the SII reflection sheet is present in Appendix D. Similar to the Year 8 study, a summary content analysis method (Hsieh & Shannon, 2005) was used as explained in Section 5.5.2 of Chapter 5. Student responses were carefully analysed, coded and themes were identified. The four categories that emerged from the analysis and some examples of student responses are presented in Table 6.10.

Further, for each category, student responses were categorised as positive and negative and the overall percentage difference of comments was obtained by comparing the percentage of positive and negative comments presented in Table 6.11.

Table 6.10: Four categories that emerged out of the coding of Year 11 chemistry students' SII qualitative data

Categories	Themes	Participants' responses
Improved Performance	Understanding of concepts, new concepts / key ideas	• I understand the concept better now. • Discussions and different views on the topic make understanding easier. • My group member explained me the concept better. • I understand how acids and bases behave in water. • Learned the basics concepts of the activity faster.
Active Learning	Focussed, attentive, involvement	• Everyone contributed in discussions. • 1-2 people did not communicate as much. • Everybody is involved in the process. • We were forced to figure out the answers ourselves. • Manager kept everyone on task.
Group Work	Helping each other, shared opinions	• Sometimes we are carried away in irrelevant talks. • Knowledge is being shared around. • We can get help from each other. • Allows everyone to work together. • Some people did not like speaking up. • We accepted and listened to everyone's opinion.
Student Satisfaction	Motivation, Enthusiasm, Time management	• It is better than learning from textbooks. • Very effective way of teaching. • Information is not clear. • Lessons are enjoyable. • We need to practice this method more so that we can use it effectively. • Teaching theory first and then do the questions. • Some people were bit slow. • More time is needed to finish the activities.

Table 6.11: Year 11 chemistry students' SII reflection data

Category	Percentage		
	Positive	Negative	Difference
Improved Performance	21	1	95.5
Active Learning	27	11	71.0
Group Work	35	22	61.4
Student Satisfaction	38	34	52.8
Total	121	68	

Improved Performance scored 21 positive and 1 negative comment with a percentage difference of 96%. Active Learning scored 27 positive and 11 negative comments and a percentage difference of 71%. This was closely followed by Group Work with 35 positive and 22 negative comments with a percentage difference of 61%. In contrast to the Year 8 study, Student Satisfaction scored the lowest percentage difference with 38 and 34 positive comments for a percentage difference of 53%.

Overall, there were 64% positive comments compared to 36% negative comments. All four categories had a positive gain which strongly supports the fact that students' do like POGIL in comparison to the teacher-centred method.

6.4.2.2 Semi-structured interviews

In the Year 11 2015 study, at the end of the POGIL intervention, six students were randomly selected for semi-structured interviews to collect additional qualitative data. The interview questions were the same as used in the Year 8 study and were categorised in three sections. The first section explored students' views on group work and collaborative learning. The questions in the second section of the interview were directed to collect some students' views about the POGIL worksheets, whereas the last section required students to answer some general questions to determine the students' overall views about the POGIL pedagogy. Student responses were carefully analysed to draw common themes to form categories as presented in Table 6.12. A copy of the interview is present in Appendix D.

Table 6.12: Four categories that emerged out of the coding of Year 11 chemistry students' semi-structured interview qualitative data

Categories	Themes	Participants' responses
Process skills	critical thinking, problem solving communication, teamwork	• Everyone contributed in the discussions and we got multiple peoples point of views. • The key questions check your understanding, as you have to apply the understanding gained to new situations. • Since we were not allowed to ask for help and were encouraged to sort it out ourselves.
Resources	Pictures,key questions	• The pictures help you process the information fast as you can clearly see the species present in the reaction. • The key questions help you to think and check your understanding. • I am a visual learner so it helps me to answer the questions.
Collaborative learning	Helping each other, sharing	• Working in groups help you understand concepts quickly. • I was able to do most of it and where I was struck, I was able to ask for help and guidance. • I enjoy collaborative learning as you get to talk a lot about things and are jovial and happy.
Satisfaction	enjoyment, fun, Negative view, better method	• I enjoyed working in groups, it gives you break from the routine structure. • A lot more fun than working from the book as we get to work with a group of people without the teacher's help. • A new way of learning adds a bit of variety and got students a little excited about the process. • My understanding has not increased really, because the teacher is not involved too much and we have to work on our own. • This method is better than learning from textbooks as we get to talk with our friends and we were more open about things.

6.5 Discussion

The present section describes the results and findings in response to research question 4. For qualitative analysis, students were given random sequential codes such as C11_14, which signifies a Year 11 chemistry student number 14. Similar to the Year 8 study, analysis of student responses to the semi-structured interviews, the SII reflection sheet, as well as teacher's observations, identified some trends as discussed below.

6.5.1 Collaborative learning

The benefits associated with the POGIL classroom teaching method were frequently mentioned in the student responses. The majority of the students (5/6) stated that group work helped them to improve their understanding of the acids and bases concepts (Ghaith, 2002). For example, student C11_13 and C11_14 said,

> *It is enjoyable and interesting to talk to the people. It involves sharing of thoughts and ideas on how to solve problems. Working in groups helps to develop your understanding as you get instant feedback from others.(C11_13)*
>
> *Working in groups help you understand concepts quickly because people have different ways of explaining things and some methods are very effective so you find it easy to understand. (C11_14)*

Similarly, highlighting the fact about group dynamics, students C11_12 and C11_15 mentioned

> *I enjoy collaborative learning as you get to talk a lot about things and are jovial and happy. In normal lessons you cannot talk and only teacher talks. My group members helped me with some answers. It has given me more confidence to ask for help and to look for answers. (C11_12)*
>
> *I was able to do most of it and where I was stuck, I was able to ask for help and guidance. It helped me understand better as you can get help from your peers. (C11_15)*

Further, SII reflection sheet results indicate that 96% of students felt that POGIL activities allowed them to work with others and this helped them to understand chemistry concepts better. The high level of Intellectual Accessibility for ASCIv2 provides evidence that students consider chemistry to be easy, organised, clear and less challenging during POGIL lessons than during normal teacher-directed lessons. During POGIL lessons, students work collaboratively and share ideas and views on given tasks among themselves and this made it possible for students with low academic ability and slow learners to get support from their peers (Oludipe & Awokoya, 2010). This is because POGIL activities are based on the learning cycle of exploration, invention and application, which supports interaction and communication with each other thus increasing students' understanding (Abdul-Kahar et al., 2016). This claim is further supported by students' statistically significant results in the 2013 diagnostic test and 2014 ABCI test after the POGIL intervention.

Based on SII reflection data, about 71% of the students shared that they were involved and participated actively in the POGIL lessons. The students worked in small groups on the worksheets that guided them through an exploration to construct understanding such as this opinion shared by student C11_13.

> *You are more focussed in the activities because you are more involved. (C11_13)*

Another student, C11_11 said,

> *Everyone contributed in the discussions and we got multiple peoples point of views. It gives different perspectives on the topic allowing it to be understood easier. (C11_11)*

Additionally, the teacher observed students during a POGIL session and took some notes, which also highlight the benefit of collaborative learning. Here are some group observations.

Everyone is focussed in the group and are participating. One student struggles to use the chemistry data sheet to write observations for the reactions. Another student helps her to use the data sheet. (Group 1)

Students are bit talkative and are reminded to stay on the task. They are working on a problem together and discussing the steps. One student is helping another student with the calculator functions. (Group 4)

The results from CUCEI also supported a high level of student involvement, i.e., during POGIL lessons, students put effort into their work and paid attention to what others are saying. Students reported that the process of knowledge construction during POGIL activities helped them to attain a better understanding of the concept. POGIL lessons provided opportunities for students to express their opinions and present their work to the class. These findings are similar to a study reported by Wanless (2012). Students also recognised the fact that group work, which is a key feature of a POGIL activity, helped them improve their conceptual understanding which is further supported by their significant achievement in the diagnostic test and ABCI test. Significant differences in Intellectual Accessibility in ASCIv2 data also indicates that students perceive chemistry to be simple, easy, and clear when they work in groups. They felt comfortable asking questions to their peers to gain better understanding of the topic at hand. Further, based on the SII reflection sheet data, 96% of students stated an increase in their conceptual understanding and about 65% of students preferred group work. These findings support the fact active collaborative learning approach enhances students' achievement in learning chemistry (Kaundjwa, 2015).

6.5.2 Resources

Almost every student perceived POGIL worksheets very beneficial such as this view shared by students C11_15 and C11_16.

Yes, pictures help you as they give you clues to answer the questions. The *key questions check your understanding, as you have to apply the understanding gained to new situations. (C11_15)*

The pictures help you process the information fast as you can clearly see the species present in the reaction. I am a visual learner so it helps me to answer the questions. The key questions help you to think and check your understanding. (C11_16)

C11_11 and C11_13 talked about the importance of key questions in the POGIL worksheets.

The key questions make you think in a logical way. The worksheet starts with easy questions and then kind of become hard. (C11_11)

The key questions on the worksheet are very important as you apply the knowledge gained to new situations. (C11_13)

These comments indicate the overall feeling of students that the key questions in the POGIL worksheets are very important, as they guide students logically to understand and attempt the questions (Vishnumolakala, 2013). However, these findings are not in line with the CUCEI survey in which Task Orientation was found to be statistically non-significant as students think the POGIL activities are not clear and well organised. One possible reason could be that many students did not understand the language of CUCEI survey items (Logan et al., 2006).

6.5.3 Process skills

Even though the interview questions did not directly ask about the process skills, students frequently mentioned that they learned some necessary skills such as problem solving, collaborative, critical thinking and communication during POGIL lessons (Hanson, 2013; Kussmaul, 2016).

For example, students C11_11 and C11_13 mentioned, *Everyone contributed in the discussions and we got multiple peoples point of views. It allows getting to know people better and enhances teamwork ability. (C11_11)*

Some questions were hard. Since we were not allowed to ask for help and were encouraged to sort it out ourselves. This probably has increased our problem-solving ability. (C11_13)

Similarly, student C11_14 said,

The key questions in the worksheet force you to find a way to answer them without the teacher's help and develop your understanding.

Further, students C11_14 and C11_15 believed that the POGIL activities provided them opportunities to enhance many skills.

A different way of learning, it is interesting and gives a chance to work collaboratively with others. Some questions in the worksheet were challenging but we managed to get most of it with each other's help. (C11_14)

The key questions check your understanding, as you have to apply the understanding gained to new situations. (C11_15)

The following excerpts from SII reflection sheets also supported the fact that POGIL sessions help them to develop these essential skills which is evident from students' reflection excerpts:

Fun and enjoyable, strong students helped weaker ones, we understood the concept as we hear different perspectives on the same topic, able to identify my mistakes, strong students directed the conversation, good communication, more socially connective, gives an end goal to achieve, group and whole class discussion helped. (Collective SII reflection comments)

The above findings clearly reflect that, use of POGIL strategy increased students process skills, a view shared by Soltis et al. (2015).

6.5.4 Attitude

Student responses also indicated that they really enjoyed the small group work aspect of the POGIL pedagogy. For example, students C11_11 and C11_15 said,

> *A lot more fun than working from the book as we get to work with a group of people without the teacher's help. It brings the class together on a more personal level and it makes lessons more enjoyable. There is more freedom to work at your own pace and how you want to do it. (C11_11)*

> *I enjoyed working in groups, it gives you break from the routine structure. It is different and you actually get a chance to present your point of view. (C11_15)*

Additional comments during the interview further supported students' excitement about POGIL lessons.

> *A new way of learning adds a bit of variety and got students a little excited about the process. (C11_13)*

The CUCEI result also supported increased student satisfaction after POGIL intervention, meaning that they enjoyed the classroom more and students consider POGIL classes interesting and not a waste of time. Students perceived that working in small self-managed teams during POGIL lessons is more beneficial as they develop content mastery through construction of their own understanding (POGIL, 2019). Contrary to the Year 8 study, more than 50% of students in Year 11 favoured group work as indicated in their SII reflection data.

A few Year 11 chemistry students held negative views about POGIL as expressed by student C11_16

> *I made new friends. However, my understanding has not increased really, because the teacher is not involved too much and we have to work on our own. Moreover, people in my group were very quiet and were not discussing much. (C11_16)*

Similarly, student C11_12 said,

> *The POGIL worksheets were all right. This method is better than learning from textbooks as we get to talk with our friends and we were more open about things. We should change groups often because sometimes we were off task and were socialising. (C11_12)*

These findings are in accordance with the opinion of Geiger (2010) that a lack of cognitive, teamwork and affective skills in students can lead to dissatisfaction by shifting teaching towards increased self-direction and greater cognitive challenge. This view is further supported by a low level of Emotional Satisfaction in the ASCIv2 results, supporting the view that many students consider chemistry as frustrating, unpleasant and complicated during POGIL lessons.

A few suggestions were also made such as by student C11_15,

> *It is a different method and you actually get a chance to present your point of view. To make it better teacher should let us decide the group every time we do this sort of activity. (C11_15)*

Similarly, students C11_14 and C11_16 supported a blended POGIL approach by saying,

> *POGIL is good if combined with teachers' assistance and we should be allowed to choose our group members. In addition, we should be given more time to finish the worksheet. (C11_14)*

> *A mix of both POGIL and teacher-centred method is good. This sort of learning is appropriate for university not high school because in university, there is time for research whereas in high school, time is limited in classrooms. In our group, some members were talkative so we need to develop good time management skills.(C11_16)*

This is further supported by the non-significant results for Personalisation in the CUCEI survey, indicating that students felt there are limited opportunities for them to interact with the teacher, so there is less teacher concern for students' welfare. Students also perceived less Individualisation based on the CUCEI survey, meaning that they did not have a greater freedom to make decisions, especially for choosing the groups as expressed by their comments.

> *The POGIL worksheets were all right. This method is better because we get to talk with our friends and we were more open about things. We should change groups often because sometimes we were off task and were socialising. (C11_12)*

> *Pictures are helpful as they enable you to understand the concept. It would have been better if they were in colour as you can identify the ions easily. Teacher had only one coloured copy, which was projected on the whiteboard. (C11_14)*

Students responses clearly demonstrate a change in view towards learning and they seemed to have gained more confidence in adapting POGIL learning. This view is further supported by the increase in mean values of all the CUCEI scales except for Innovation, meaning students perceived that their teacher does not try new teaching techniques which is contrary to the results indicated by the student interviews as mentioned by students C11_12, C11_13, C11_14 and C11_15.

The process of data triangulation showed that students were open to POGIL lessons, and that there are benefits associated with this teaching-learning approach which are not available through traditional teaching methods. These findings are in accordance with those of Haryati (2018), that the POGIL model has a positive influence on both students' conceptual understanding as well as process skills. In a POGIL classroom, students work in small groups on specially designed guided inquiry worksheets (Hanson, 2013). However, there is no "one size fits all" teaching approach (Geiger, 2010), as in this research with Year 11 students, there were a few disagreements associated with group dynamics and level of teacher assistance. The blended POGIL approach (Murphy et al., 2010; Southam, 2011) could easily solve some concerns raised by students on the ways in which the activities could be improved to increase their learning with comments such as "when introducing a new topic the teacher should discuss it a little more" and "content background should be provided before the activities". The same view is shared by Williamson et al. (2013) who suggested to adopt a hybrid approach which is more acceptable to most students.

6.6 Summary

The third research question (RQ3) in relation to this Year 11 study, used quantitative measures to investigate whether or not there were any differences in students' achievement based on selected diagnostic tests and school-based tests in chemistry after the teaching intervention. The mean score of multiple-choice questions test and ABCI diagnostic test have shown a statistically significant increase in students' achievement in chemistry when taught using the POGIL pedagogy.

To answer the fourth research question (RQ4), both qualitative and quantitative methods were used to investigate students' perceptions about the POGIL pedagogy. The quantitative data was collected using CUCEI and ASCIv2 surveys. According to CUCEI results, students favoured greater involvement and satisfaction in teaching approaches and the ASCIv2 results demonstrated that students seem to find learning chemistry easier and less challenging. The qualitative analysis of semi-structured interviews and students' responses to the SII reflection sheets indicated a positive impact of POGIL on conceptual understanding as well as developing process skills. To overcome some disagreements, a few students suggested using a blended POGIL approach that involved use of both POGIL and traditional teaching.

Chapter 7

Major Findings and Conclusions

7.1 Introduction

The chapter presents a summary of the major findings and conclusions related to this study as well as suggesting some recommendations on how the POGIL pedagogy can be implemented in Australian schools. The summary of each chapter of this thesis (Section 7.2) and major findings pertaining to the four research questions of this study (Section 7.3) are presented. Based on teacher as a researcher model in the present study, the researcher reflected on POGIL's implementation in her classes (Section 7.4). This chapter also highlights the limitations of this study (Section 7.5) and outlines the recommendations and implications based on the research findings (Section 7.6) followed by conclusion of this study (Section 7.7).

7.2 Summary of the thesis

POGIL is reported to have been successfully implemented in tertiary chemistry classes (Bedgood et al., 2010; Farrell et al., 1999). However, there is little research on the use of POGIL in secondary chemistry classrooms, and none in lower secondary classrooms (Barthlow, 2011). Moreover, the implementation of POGIL remains unaddressed in Australian secondary classes. Being the first study in Australian secondary classes, the aim of this research study was to evaluate the efficacy of POGIL in Australian lower and upper secondary chemistry classes and to demonstrate its cross-cultural utility as a pedagogy to address key curricular aims in these settings for science inquiry skills.

The first chapter of the thesis described the background and significance to evaluate the efficacy of POGIL in Australian secondary science classes. It also outlined the objectives and four research questions of this study, which are further described along with the general findings in Section 7.3.

In Chapter 2, the literature review on curriculum and theoretical framework required for this study was presented. The review explained the abstract and complex nature of chemistry, leading on to how the human brain processes information. It outlined the cognitive models of learning and literature regarding POGIL's characteristics, effectiveness and implementation. Studies on students' perceptions, methodologies for investigating students' understanding and action research were reviewed. It also presented the information on the development and focus of the Australian curriculum.

Chapter 3 presented the research design for the Year 8 and Year 11 studies based on a curriculum evaluation model developed by Keeves (1995). The present action research study used a quasi-experimental design and adopted a mixed-method approach by using both questionnaires and semi-structured interviews together as a source of the data collected (Creswell, 2009). The Year 8 study involved a pre- and post-test two-group design, whereas the Year 11 study included a pre- and post-test one-group design. Both studies were conducted in two cycles.

Chapter 4 reported the results and findings in response to research questions 1 and 2 on the adaptability and integration of POGIL in the Australian curriculum and on the implementation of POGIL in the Australian classrooms. To answer the first research question, curriculum documents from the Australian curriculum were analysed and mapped with the POGIL process skills. To answer the second research question, POGIL worksheets were integrated in the Australian curriculum and the researcher implemented the POGIL worksheets her classroom. The qualitative data was collected using teacher's observations, students' reflection sheets and semi-structured interviews.

Chapter 5 presented the results and findings of Year 8 students' understanding of the "matter" concept and were used to address research question 3. It also presented data about students' perceptions of their learning in the POGIL classroom, which was used to address research question 4. For answering the third research question, data was obtained from 100 Year 8 students in 2013 and 2014, using an end of topic test, a multiple-choice questions test and Particle Theory Diagnostic Instrument (PTDI) diagnostic test. To answer the fourth research question, Science Laboratory Environment Inventory (SLEI) and Attitude towards the Subject of Chemistry Inventory, version 2 (ASCIv2) questionnaires were used to collect quantitative data from 100 Year 8 students, whereas students' Strengths, areas for Improvement, and Insights (SII) reflection sheets, teacher's observations and semi-structured interviews were used to collect the qualitative data.

Chapter 6 presented the results and findings of Year 11 chemistry students understanding of acid-base concepts to address research question 3, as well as students' perceptions of their learning in the POGIL classroom, to address research question 4. For answering the third research question, data was collected from 33 Year 11 students in 2013 and 2015, using an acid-base topic test, a multiple-choice questions test and Acid-Base Reactions Concept Inventory (ABCI). To answer the fourth research question, Attitude towards the Subject of Chemistry Inventory, version 2 (ASCIv2) and College and University Classroom Environment Inventory (CUCEI) questionnaires were used to collect quantitative data from 33 Year 11 students. The qualitative data was collected using students' Strengths, areas for Improvement, and Insights (SII) reflection sheets, teacher's observations and semi-structured interviews.

The present chapter provides the summary of the major findings of this study and focuses on the limitations of the present study as well as recommendations for future research and implications for practice.

7.3 Findings with regard to the research questions

The aim of this research study was to evaluate the efficacy of Process Oriented Guided Inquiry Learning (POGIL) — a student centred pedagogy in Australian secondary science classes. The following sections focus on the findings of study in context of the research questions.

7.3.1 Research question 1

Is POGIL a good match with the existing intended Australian science curriculum?

The intended Australian curriculum for Year 8 chemical science and Year 11 chemistry as described in Chapter 4, were analysed to see if POGIL process skills can be linked with Australian Science Inquiry Skills (SIS), Science Understanding (SU) and general capabilities. The Australian science curriculum (chemistry) and POGIL process skills were found to be aligned with each other with some skills common to both (see Chapter 4, Tables 4.7, 4.8 and 4.9). Studies have reported that POGIL activities can be incorporated successfully to develop both the content knowledge as well as the process skills (Cole & Bauer, 2008; Soltis et al., 2015; Straumanis & Simons, 2008; Vishnumolakala, 2013). Educators have the flexibility to create or select worksheets from a pool of online resources to address their schools' curriculum requirements. Writing POGIL activities can be challenging and time consuming, however, once created they become a useful resource which teachers can share with others teachers' and schools. As evident in Table 4.9 (Chapter 4), the complimentary relationship between ACARA's general capabilities and the process skills in POGIL are transparent from the nature of the POGIL materials, interactions of the students', and the author's experience in facilitating POGIL.

7.3.2 Research question 2

Is there any evidence that POGIL is culturally transferable to an Australian science classroom and can be implemented to address its curriculum?

This research question corresponds to the implemented curriculum as described in Chapter 4 and explored the implementation of POGIL in the Australian classrooms. The study used a teacher as a researcher model and a mixed-method triangulation of both qualitative and quantitative data to answer this question. The results from the analysis of the teacher's observations of POGIL sessions, students' SII reflection sheets and semi-structured interviews indicated that the implementation of POGIL in the Australian classrooms is consistent with other studies from the literature (Brown, 2010b; Geiger, 2010; Vishnumolakala, 2013). Students have reported that working collaboratively on POGIL activities have improved their conceptual understanding along with essential process skills like communication, group work, critical thinking and problem solving as evident in Table 4.9 (Chapter 4). The data analysed and described in Section 4.8 of Chapter 4, provides strong evidence that skills required for POGIL learning were implemented. The findings from the present research may help Australian students develop their general capabilities as well as their science inquiry skills. As conceivable from students' SII reflection sheets responses, the teacher's observations and semi-structured interviews, the majority of the students were supportive of collaborative learning. However, there were few issues regarding group dynamics and student engagement. In the Year 8 classes, there were some behavioural issues such as disagreements amongst the group members as few students were hesitant to work with others (Soltis et al., 2015). This led to students not being actively engaged in group discussions. In comparison, the Year 11 students were more mature and accommodating to each other and there were less behavioural problems during the POGIL session. With some careful consideration while forming groups, such as setting clear group expectations and well-designed POGIL activities, POGIL can be successfully implemented in Australian science classrooms.

7.3.3 Research question 3

Are there any differences in students' achievement in selected diagnostic tests and school-based tests in chemistry after the teaching intervention?

This research question focussed on the achieved curriculum described in Chapter 5 for the Year 8 study, and in Chapter 6 for the Year 11 study. Both Year 8 and Year 11 studies showed a statistically significant difference between students' pre- and post-test scores in selected diagnostics tests and school-based tests supporting POGIL having a positive effect on students' achievement. As discussed in Chapter 5 and Chapter 6, students in both studies mentioned in their SII reflection sheets and semi-structured interviews that working collaboratively in groups helped them to improve their understanding of the concepts. The results from both Year 8 and Year 11 study are presented in Table 7.1.

Table 7.1: Statistical analysis of Year 8 and Year 11 tests to answer research question 3

Assessment	Chapter reference	Statistical analysis	Result
Year 8 study, 2013 and 2014 Matter topic test	Chapter 5, Section 5.2	Mixed-model ANOVA	Statistically significant with a medium effect size.
Year 8 study, 2013 matter diagnostic test	Chapter 5, Section 5.4	Mixed-model ANOVA	Statistically significant with a medium effect size.
Year 8 study, 2014 PTDI	Chapter 5, Section 5.4	Wilcoxon test	Statistically significant with a medium effect size.
Year 8 study, 2013 and 2014 SII reflection	Chapter 5, Section 5.5.2	Improved performance with 60%, positive percentage difference	POGIL had positive impact on students' conceptual gains
Year 11 study, 2013 acid-base diagnostic test	Chapter 6, Section 6.3	Paired samples t-test	Statistically significant with a medium effect size.
Year 11 study, 2015 ABCI	Chapter 6, Section 6.3	Wilcoxon test	Statistically significant with a large effect size
Year 11 study, 2013 and 2015 SII reflection	Chapter 6, Section 6.4.2	Improved performance with 96%, positive percentage difference	POGIL had positive impact on students' conceptual gains

In conclusion, the POGIL pedagogy that was used in the present study has proven to be very effective in improving students' understanding of matter (Year 8) and acid-base (Year 11) concepts. Overall, these results are consistent with other studies which demonstrated a similar impact (Bowen, 2000; Lewis & Lewis, 2005; Straumanis & Simons, 2008).

7.3.4 Research question 4

What are students' perceptions about the POGIL lessons?

This research question was concerned with the perceived curriculum described in Chapter 5 for the Year 8 study, and in Chapter 6 for the Year 11 study. For triangulation purposes, a mixed-method approach was used by collecting both quantitative and qualitative data as presented in Table 7.2.

The findings from both the Year 8 study and Year 11 study revealed that students considered POGIL to be their preferred learning environment compared to traditional teacher-centred pedagogy. Students perceived that working collaboratively on POGIL activities increased their thinking and problem solving skills. Analysis of students' attitudes from their ASCIv2 scores, for both Year 8 and Year 11 study also demonstrated an increase in students' intellectual accessibility, as they helped each other to solve the hard and challenging problems (Brandriet et al., 2011). Following the qualitative analysis of students' responses on the SII reflection sheets and the data obtained from semi-structured interviews, it was found that the majority of students held positive views about POGIL learning, similar to other studies such as Brown (2010a), Farrell et al. (1999), Lewis and Lewis (2005), and Soltis et al. (2015). Students mentioned that by actively engaging in small group discussions in a POGIL class, not only did their understanding of chemistry increase, but it has also helped in the development of process skills such as collaborative, problem solving, critical thinking and communication (see Chapter 5 and 6). The findings are consistent with previous studies (Soltis et al., 2015; Vishnumolakala, 2013).

However, caution should be taken in adopting a 'one-size fits all' educational approach, as some students considered that POGIL learning was not effective due to a lack of collaboration between group members. In the Year 8 study, some students expressed their discontent with POGIL, as revealed by students' semi-structured interview responses and the SII data. The main reason for this dissatisfaction was group work and the associated social dynamics within the heterogeneous groups (see Chapter 5, Section 5.6). In the Year 8 group, teacher also noticed some behavioural problems such as a

Table 7.2: Statistical analysis of Year 8 and Year 11 tests to answer research question 4

Assessment	Chapter reference	Statistical analysis	Result
Year 8 study, 2013 and 2014 SLEI	Chapter 5, Section 5.5.1	Mixed-model ANOVA	Statistically significant effect on Student Cohesiveness with a large effect size. Rule Clarity was found to be significant for the control group with a small effect size.
Year 8 study, 2013 ASCIv2	Chapter 5, Section 5.5.1	Mixed-model ANOVA	Statistically significant effect on Intellectual Accessibility with a large effect size.
Year 8 study, 2013 and 2014 SII reflection	Chapter 5, Section 5.5.2	Active Learning, Group Work, Student Satisfaction and Improved Performance indicated a positive percentage difference	Positive evidence of impact of POGIL on process skills.
Year 11 study, 2013 and 2015 CUCEI	Chapter 6, Section 6.4.1	Mixed-model ANOVA	Statistically significant effect on Involvement and Satisfaction with a large effect size.
Year 11 study, 2013 and 2015 ASCIv2	Chapter 6, Section 6.4.1	Mixed-model ANOVA	Statistically significant effect on Intellectual Accessibility with a large effect size.
Year 11 study, 2013 and 2015 SII reflection	Chapter 6, Section 6.4.2	Active Learning, Group Work, Student Satisfaction and Improved Performance indicated a positive percentage difference	Positive evidence of impact of POGIL on process skills.

lack of collaboration, off-task talking, and arguments, which are consistent with previous studies (Backer et al., 2018). Further, as advised by Backer et al. (2018), middle school students benefit from integrating collaborative learning activities when preceded by intended group formation and re-teaching of group skills.

In the Year 11 study, the teacher noticed that majority of students had no behavioural problems and they worked effectively (see Chapter 4, Section 4.7.3). However, a few students expressed their dissatisfaction with POGIL primarily because there was a lack of teacher interaction and group dynamics (see Chapter 6, Section 6.5). A blended POGIL approach could easily address these concerns raised by the students as also noted by Murphy et al. (2010). Every individual learns differently, and they need to have a variety of ways of learning to strengthen their foundation in chemistry. Therefore, it is very important to make a balance between traditional teaching and POGIL learning experiences so that students can coherently achieve their learning goals.

7.4 Reflection

As a teaching pedagogy, POGIL has gained the momentum to cater for the essential skills required in the 21st century, by providing an active and student-centred environment (Hale & Mullen, 2009; Haryati, 2018; Vishnumolakala et al., 2017). As an educator, it is my responsibility to equip students with life-long skills by implementing the best possible pedagogical practices that also created the opportunity to carry out the present study.

Trialling POGIL was an insightful experience for me as a teacher as I could improve my teaching and learning style, as well as improve my students' learning experiences. Both my students and I believed that we could be a part of this study and make meaningful contributions. Initially, I was not familiar with the key features of POGIL worksheets and its implementation. However, by reviewing videos, talking to experienced POGIL practitioners', and understanding the learning cycle on which this pedagogy is based on, I was able to establish the full value of POGIL. The POGIL activities were developed based on the principle that students learn better when they explore models to answer carefully designed questions by working together in small self-managed groups.

An experienced POGIL practitioner assisted me in developing the POGIL activities for the Year 8 class. After the initial struggle to write some POGIL activities for the Year 8 study, I began to gain confidence in understanding and adopting this approach. I will continue to modify and create these activities and incorporate them in my classes. For the Year 11 study, I used the POGIL activities already created and shared by other people that matched and covered the Year 11 chemistry content. POGIL was initially implemented in 2013, for both the Year 8 and Year 11 study.

The first few POGIL sessions were not perfect as students struggled to follow the group norms and time management. The Year 8 students could not finish the whole worksheet in one lesson, so the remaining questions were given as homework and were followed up in the following lesson. There were also some behavioural problems in the Year 8 class such as disagreements and a lack of an active discussion environment, so I had to change a few students groups. However, the Year 11 students were happy to adapt to this pedagogy and there were fewer behavioural problems. By the time students got to the last few activities, they became very confident and even without teachers instructions, they knew what they needed to do.

After seeing some positive outcomes in the 2013 study, I decided to repeat the study in 2014 with the Year 8 class and again in 2015 with the Year 11 class, but this time using some robust measures to ensure the reliability and validity was maintained. I used PTDI with the 2014 Year 8 class and ABCI with the 2015 Year 11 class instead of a teacher-based multiple-choice questions test. Semi-structured interviews were conducted to collect more qualitative data. A majority of the Year 8 and Year 11 students responded positively to POGIL. However, some Year 11 students were dissatisfied with POGIL as they felt there was less teacher interaction.

As I was not very impressed by the initial implementation of POGIL, some modifications were made following discussions with the supervisor. Before the start of the POGIL sessions, I spent a lesson creating groups, and explaining the different roles and the group norms to the students. I also modified some POGIL worksheets and removed some questions to allow time for me to discuss the worksheet answers. During the second implementation of POGIL for Year 8 and Year 11 in 2014 and 2015 respectively, I became more confident with the sessions and was able to guide my students better.

7.5 Limitations

As with the majority of studies, the design of the current study is subject to some potential limitations. Care was taken in controlling the confounding variables in the Year 8 control and treatment groups (see Chapter 5, Section 5.2). However, the inherent characteristics such as social behaviour, intelligence and socioeconomic status of the school and its population of students, as well as the place of research study limits the generalisability of the present study to other contexts (Compeau et al., 2012). The limitations of this study are discussed as follows.

7.5.1 The sample

The reported results are based on data collected from a convenient sample of senior high school students in a single school. For the Year 11 study, the sample size was very small and was not representative of the Australian student population as a whole. A larger sample size may have produced different or additional themes in the qualitative data. Moreover, the Year 11 study was limited to only one chemistry class as there was no control or comparison group.

7.5.2 Instruments

Another potential limitation could be survey exhaustion. The researcher noticed that some students chose the same alternative for consecutive items. Both SLEI (35 Items) and CUCEI (49 items) are long and students may not have spent quality time and effort finishing the survey (Nguyen, 2017). Additionally, there were no significant differences in the Year 8 SLEI survey for Material Environment findings. This could be due to students not having an in-depth understanding of the results required in the pre data collection, and therefore no significant differences were observed in the post survey. This is a limitation for this study and further research will be required to explore any environmental differences.

Also, misinterpretation of survey questions may have possibly compromised the accuracy of the student responses (Baer et al., 1997), therefore the results may not have been valid. Both surveys have some negatively worded items and despite a careful explanation of the negatively worded items, the researcher noticed some ambiguity in the responses. The negatively worded statements may have confused some students making it difficult to choose the correct response (Logan et al., 2006). The CUCEI instrument results used for the Year 11 study were found to be theoretically mis-matched with observed findings from the qualitative data (see Chapter 6, Section 6.5). Other reliable instruments would be better to measure students' perceptions of a POGIL classroom.

7.5.3 Teacher as a researcher

Another limitation of the study was the teacher acting as a researcher, and thus taking on two roles. Having to facilitate the POGIL lesson and write observational notes and observe the behaviour of so many students was difficult. This was especially difficult in the initial stages of the Year 8 class POGIL sessions because there were some behavioural problems. Having additional external observers in the classroom or video recording the sessions could have addressed this limitation.

7.5.4 POGIL Worksheets

In some POGIL worksheets, particles were represented in different colours such as Model 4.4 (Year 8 study) and Model 4.6 (Year 11 study). This is a potential limitation as the colourfulness of particles might have resulted in some alternative conceptions. In the present study, POGIL worksheets were used in a guided inquiry setting, where students were provided with different forms of other representations for particles, such as pictorials and symbolic. This reduces the potential for students to form alternative conceptions.

7.6 Recommendations and implications for practice

Being the first time that POGIL has been implemented in Australian secondary and senior secondary chemistry classes, future POGIL instructors can build up their level of teaching skills by implementing the recommendations from this study as follows:

- Students in both year groups were unfamiliar with group learning or active learning and there was a big jump to move them into the POGIL process. Educators must prepare students for the change in teaching style. Also, the students at Year 8 level were not always positive about working in groups as compared to the Year 11. While working with this age group, educators must consider the social dynamics when forming heterogeneous groups to enhance collaborative skills thus fostering positive interdependence (Aggarwal & O'Brien, 2008; Wilhelm, 2007). Before starting POGIL sessions, the teacher must establish a clear set of rules and expectations to be followed by each group member and should not put more than four students in a group (Johnson & Johnson, 2009; Johnson & Johnson, 1986).

- New POGIL instructors should consider starting with one POGIL session once or twice a week, until both the instructors and students are comfortable with the process and instructor can assess POGIL's implementation. A new adopter of POGIL should refer to the POGIL website for resources including videos for implementation POGIL (2019).

- For the present study, the sample size was small especially for the Year 11 chemistry study. However, the results from this study are very encouraging and should be validated by a larger sample size in different schools in various socio-economic areas, which would better represent the Australian school student population.

- This study focussed on the effect of POGIL on students, and their understanding of chemistry. Further studies in different learning areas or longitudinal studies involving the impact of POGIL on secondary school students' learning and attitudes are recommended to provide future POGIL instructors with a more comprehensive view about student learning in a POGIL classroom.

- The duration that POGIL is implemented for is an important factor to take into consideration, as high school students need more time to adapt to this new pedagogy. A minimum of 7-8 weeks of POGIL teaching is required before introducing a teaching intervention.

- Year 11 students' reservations could not be prevented as they felt a lack of teacher interaction which was their usual expectation. A blended approach consisting of POGIL and traditional teaching, rather than one or the other can solve this problem. Educators should incorporate POGIL activities within the course, rather than having the course solely about POGIL. Hence, POGIL activities should be used in conjunction with other teaching pedagogies to remove such problems and cater for the needs of diverse students. Moreover, a blended approach is suitable considering that preparation for POGIL teaching is time consuming and also that students need to have a variety of ways of learning.

- General capabilities play an important role in the Australian curriculum because they prepare young Australians to face the challenges of the 21st century. Teachers are expected to teach and incorporate general capabilities in their learning area content. It has been recognised in this study that POGIL activities address not only general capabilities, but also science inquiry skills. The present findings have important implications and could benefit the school educators in enhancing their skills and provide them with a tool to address their students' curriculum needs.

7.7 Conclusion

To conclude, the present study has established that in POGIL classrooms, students made positive cognitive and affective gains. This research demonstrated the efficacy of meeting Australian science curricular goals on a number of dimensions using this pedagogy and supports further implementation of POGIL.

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Appendix A

Approval letters

Government of **Western Australia**
Department of **Education**

Your ref :
Our ref : D13/0123642
Enquiries :

Mrs Aneeta Dogra
[redacted]

Dear Mrs Dogra

Thank you for your completed application received 17 December 2012 to conduct research at a Department of Education site.

The focus and outcomes of your research project, *Process Oriented Guided Inquiry Learning in Australia secondary science classrooms: a model pedagogy to develop science inquiry skills,* are of interest to the Department. I give permission for you to approach the Principal of [redacted] to invite his school's participation in the Year 8 component of your research only, as outlined in your application. It is a condition of approval, however, that upon conclusion the results of this study are forwarded to the Department at the email address below.

Consistent with Department policy, participation in your research project will be the decision of the Principal of [redacted], individual staff members, the students at that school and their parents. A copy of this letter must be provided to the Principal when requesting his participation in the research. Researchers are required to sign a confidential declaration and provide a current Working with Children Check upon arrival at the Department of Education site.

Responsibility for quality control of ethics and methodology of the proposed research resides with the institution supervising the research. The Department notes a copy of a letter confirming that you have received ethical approval of your research protocol from the Curtin University Human Research Ethics Committee.

Any proposed changes to the research project will need to be submitted for Department approval prior to implementation.

Please contact Ms Joanna Devereux, Research and Evaluation Assistant, on (08) 9264 5512 or researchandpolicy@education.wa.edu.au if you have further enquiries.

Very best wishes for the successful completion of your project.

Yours sincerely

ALAN DODSON
DIRECTOR
EVALUATION AND ACCOUNTABILITY

18 March 2013

Government of **Western Australia**
Department of **Education**

Your ref :
Our ref : D13/0244337
Enquiries :

Mrs Aneeta Dogra
[redacted]

Dear Mrs Dogra

Thank you for your completed application received 8 May 2013 to conduct research on Department of Education sites.

The focus and outcomes of your research project, *Process Oriented Guided Inquiry Learning in Australia secondary science classrooms: a model pedagogy to develop science inquiry skills*, are of interest to the Department. I give permission for you to approach site managers to invite their participation in the Year 11 component of your project, as outlined in your recent emails to the Department. It is a condition of approval, however, that upon conclusion the results of this study are forwarded to the Department at the email address below.

Consistent with Department policy, participation in your research project will be the decision of the schools invited to participate, individual staff members, the children in those schools and their parents. A copy of this letter must be provided to site managers when requesting their participation in the research. Researchers are required to sign a confidential declaration and provide a current Working with Children Check upon arrival at the Department of Education site.

Responsibility for quality control of ethics and methodology of the proposed research resides with the institution supervising the research. The Department notes a copy of a letter confirming that you have received ethical approval of your research protocol from the Curtin University Human Research Ethics Committee.

Any proposed changes to the research project will need to be submitted for Department approval prior to implementation.

Please contact Ms Joanna Devereux, Research and Evaluation Officer, on (08) 9264 5512 or researchandpolicy@education.wa.edu.au if you have further enquiries.

Very best wishes for the successful completion of your project.

Yours sincerely

ALAN DODSON
DIRECTOR
EVALUATION AND ACCOUNTABILITY

15 May 2013

Appendix B

Consent letters

Appendix B
Department of Chemistry
PARENT Information Sheet

My name is Aneeta Dogra. I am a Science teacher at [redacted]. I am currently completing a piece of research for my Doctor of Philosophy (Chemistry) at Curtin University.

Purpose of Research

I am investigating the research topic "An exploration of Process Oriented Guided Inquiry Learning in secondary chemistry classes". POGIL is a student centred learning method where students construct their own learning based on the information provided and then they apply the knowledge they have gained to the new situations. The effectiveness of POGIL on students learning outcomes and science inquiry skills will be the focus of this research study.

My Role

This project aims to develop and adapt learning objects for use in Australian secondary classes. The school principal has already been contacted and has agreed to the project. The activities based on POGIL method will be incorporated in the topic "Matter" so that there is no disruption to student's learning. I intend to start this study in week 7 of term 1 and it continues till week 5 in term 2.

Your Child's role

I will conduct research by asking for your child to take part in:

-Short diagnostic tests. The results of the tests will be given back to your child after the completion of the tests. The tests will not in any way affect your child's reported grades.

-He/she will be given a short 15 minute questionnaire and may also be interviewed to provide feedback about the research method. My colleague will interview them and the interviews will take place at school. He will randomly select 4-5 students from the class. He will remove students name and other identifying information before giving me the responses. Again this participation will be voluntary and of short duration (10-15 mins).

I also seek your permission to use your child's grade for the end of topic test on matter in this research study.

Consent to Participate

I want to assure you that there are no consequences that arise from you or your child's decision to participate or not. There will be no difference in the way instruction and support in the classroom is provided to children regardless of whether or not they participate in the research. I have fully informed the principal of the proposed research and if you feel there are pressures or unanticipated consequences as a result of participating or not, you should contact Mr Paul Billing on 93762100 or one of the other contactable people provided at the end of this letter.

Your child's involvement in the research is entirely voluntary. You have the right to withdraw at any stage without it affecting your rights, or the rights of your child, or my responsibilities.

Please discuss this with your child. Your child has also been given a consent form to sign. When you have signed the consent form I will assume that you have agreed to have your child participate and allow me to use your child's data in this research.

Confidentiality and what happens to the information collected
The information your child will provide will be kept separate from your child's personal details, and only myself and my supervisor will only have access to this.

The interview transcript, and all other information collected will not have your child's name or any other identifying information on it and in adherence to university policy, will be kept in a locked cabinet for at least five years, before a decision is made as to whether it should be destroyed. The data will be used only for this project and will not be used in any extended or future research without first obtaining explicit written consent from you and your child.

It is intended that the findings of this study will be published in my doctoral thesis and in peer reviewed journal articles. A summary of the research findings will also be made available upon completion of the project. You can access this by visiting Curtin University's library thesis repository, where we expect it to become available after August, 2016.

Further Information
This research has been reviewed and given approval by Curtin University of Technology Human Research Ethics Committee (Approval Number RD-56-12) and has met the policy requirements of the Department of Education and Training. If you would like further information about the study, please feel free to contact me by email aneeta.dogra@student.curtin.edu.au. Alternatively, you can contact my supervisor Dr. Daniel Southam on 9266 2380 or email D.Southam@curtin.edu.au.

Thank you very much for your involvement in this research.

If you are willing for your child to participate, please sign the consent form and return it to me.

Your participation is greatly appreciated.

Curtin University

PARENT Consent Form

• I have read the information sheet and understand the purpose and procedures of the study.

• I have been provided with the participation information sheet.

• I understand that the procedure itself may not benefit my child.

• I understand that my and my child's involvement is voluntary and we can withdraw at any time without problem.

• I understand that no personal identifying information like my name and address will be used in any published materials.

• I give permission to use my child's results for school based test on the topic matter.

• I understand that all information will be securely stored for at least 5 years before a decision is made as to whether it should be destroyed.

• I have discussed with my child what it means to participate in this research study and he/she has agreed to participate as indicated by the signed student's consent form.

• I have been given the opportunity to ask questions about this research.

• I agree to allow my child to participate in the study outlined to me.

Parent's Name: ____

Student's Name: ____

Parent's Signature: ____

Date: ______________________

Appendix B
Department of Chemistry
STUDENT Information Sheet

Curtin University

My name is Aneeta Dogra. I am currently completing a piece of research for my Doctor of Philosophy (Chemistry) at Curtin University.

Purpose of Research

I am investigating the research topic "An exploration of Process Oriented Guided Inquiry Learning in secondary chemistry classes". POGIL is a student centred learning method where students construct their own learning based on the information provided and then they apply the knowledge they have gained to the new situations. The effectiveness of POGIL on students learning outcomes and science inquiry skills will be the focus of this research study.

My Role

This project aims to develop and adapt learning objects for use in Australian Secondary classes. The school principal has already been contacted and has agreed to the project. The activities based on POGIL method will be incorporated in the topic "Matter" so that there is no disruption to student's learning. I will conduct research by asking for you to take part in the following activities:

-Short diagnostic tests on chemistry that will complement your learning. The results of the tests will be given back to you after the completion of the tests. The tests will not in any way affect your reported grades.

-A 15 minute questionnaire and I may also ask for your participation in a short interview to provide feedback about the research method. Another science teacher will conduct these interviews at school. He will randomly select 4-5 students from the class. He will remove students name and other identifying information before giving me the responses. Again this participation will be voluntary and of short duration (10-15 mins).

-I also seek your permission to use your grade for the end of topic test on matter in this research.

Consent to Participate

I want to assure you that there are no consequences that arise from your decision to participate or not. There will be no difference in the way instruction and support in the classroom is provided to you regardless of whether or not you participate in the research.

I have fully informed the principal of the proposed research and if you feel there are pressures or unanticipated consequences as a result of participating or not, you should contact Mr Paul Billing on 93762100 or one of the other contactable people provided at the end of this letter.

Your involvement in the research is entirely voluntary. You have the right to withdraw at any stage without it affecting your rights or my responsibilities. When you have signed the consent form I will assume that you have agreed to participate and allow me to use your data in this research.

Confidentiality

The information you provide will be kept separate from your personal details, and only myself and my supervisor will only have access to this. The interview transcript and all other information collected will not have your name or any other identifying information on it and in adherence to university policy, will be kept in a locked cabinet for at least five years, before a decision is made as to whether it should be destroyed.

The information will only be used for this project and will not be used in any extended or future research without first obtaining explicit written consent from you and your parent.

Further Information

This research has been reviewed and given approval by Curtin University of Technology Human Research Ethics Committee (Approval Number RD-56-12) and has met the policy requirements of the Department of Education and Training. If you would like further information about the study, please feel free to contact me by email aneeta.dogra@student.curtin.edu.au. Alternatively, you can contact my supervisor Dr. Daniel Southam on 9266 2380 or email D.Southam@curtin.edu.au.

If you are willing to participate, please sign the consent form and return it to me.

Thank you very much for your involvement in this research.

Your participation is greatly appreciated.

STUDENT Consent Form

• I have read the information sheet and understand the purpose and procedures of the study.

• I have been provided with the participation information sheet.

• I understand that the procedure itself may not benefit me.

• I understand that my involvement is voluntary and I can withdraw at any time without problem.

• I understand that no personal identifying information like my name and address will be used in any published materials.

• I give permission for my grade for school based test on matter will be used in the study.

• I understand that all information will be securely stored for at least 5 years before a decision is made as to whether it should be destroyed.

• I have been given the opportunity to ask questions about this research.

• I agree to participate in the study outlined to me.

Participant's Name: ______________________

Signature: ___________________

Date: ______________________

Appendix B
Department of Chemistry
TEACHER Information Sheet

My name is Aneeta Dogra. I am currently completing a piece of research for my Doctor of Philosophy (Chemistry) at Curtin University.

Purpose of Research

I am investigating the research topic "An exploration of Process Oriented Guided Inquiry Learning in secondary chemistry classes". I will explore the adaptability of Process Oriented Guided Inquiry Learning (POGIL) method to Australian Secondary Science classes and its alignment with the National Curriculum and local curricula. POGIL is a student centred learning method where students construct their own learning based on the information provided and then they apply the knowledge they have gained to the new situations. The effectiveness of POGIL on students learning outcomes and science inquiry skills will be the focus of this research study.

Your Role

I will conduct research by asking your class to take part in short diagnostic test on chemistry that will complement your teaching. The school principal has already been contacted and has agreed to the project. Students involved will undertake a number of short diagnostic tests. The results of the tests will be given back to you after the completion of the test. The diagnostic tests will not in any way affect your students reported grades. Students will also be given a 15 minutes questionnaire. I intend to use students school based test grades on the topic matter and will be seeking permission from the parents.

Consent to Participate

I want to assure you that there are no consequences that arise from your decision to participate or not. I have fully informed the principal of the proposed research and if you feel there are pressures or unanticipated consequences as a result of participating or not, you should contact Mr Paul Billing on 93762100 or one of the other contactable people provided at the end of this letter.

Your involvement in the research is entirely voluntary. You have the right to withdraw at any stage without it affecting your rights or my responsibilities. When you have signed the consent form I will assume that you have agreed to participate and allow me to use your data in this research.

Confidentiality

The information you and your students provide will be kept separate from the personal details, and only myself and my supervisor will only have access to this. In adherence to university policy, the information will be kept in a locked cabinet for at least five years, before a decision is made as to whether it should be destroyed.

The identity of participants and the school will not be disclosed at any time, except in circumstances that require reporting under the Department of Education *Child Protection* policy, or where the research team is legally required to disclose that information. Participant privacy, and the confidentiality of information disclosed by participants, is assured at all other times. The data will be used only for this project, and will not be used in any extended or future research without first obtaining explicit written consent from participants.

Further Information

This research has been reviewed and given approval by Curtin University of Technology Human Research Ethics Committee (Approval Number RD-56-12) and has met the policy requirements of the Department of Education and Training. If you would like further information about the study, please feel free to contact me by email aneeta.dogra@student.curtin.edu.au. Alternatively, you can contact my supervisor Dr. Daniel Southam on 9266 2380 or email D.Southam@curtin.edu.au.

If you have had all questions about the project answered to your satisfaction, and are willing to become involved, please complete the **Consent Form** on the next page.

This information letter is for you to keep.

Thank you,

Yours truly,

ANEETA DOGRA

Student ID 15907808
Curtin University

Curtin University

Consent Form for Teachers

- I have read and understood the information letter about the project, or have had it explained to me in language I understand.

- I have taken up the invitation to ask any questions I may have had, and am satisfied with the answers I received.

- I understand that participation in the project is entirely voluntarily.
- I am willing to become involved in the project, as described.

- I understand I am free to withdraw that participation at any time without affecting my relationship with the researcher.
- I give permission for my contribution to this research to be *published in research journals*, provided that I or the school is not identified in any way.

- I understand that I can request a summary of findings once the research has been completed.

Name of Participant : __________________________________

Signature of Participant: __________________________________

Date: / /

Appendix C

Tests

Appendix C
Diagnostic Test Matter
Year 8

Directions

- This test contains 11 questions related to concept of matter.
- Read the question carefully.
- Record your answer by putting cross on the initial of the chosen answer.

1. Name the three states of matter and give an example for each.

____

____

____

2. Which statement is true?

a) only solids can be compressed.
b) gases, liquids and solids can be compressed.
c) gases can be compressed but solids and liquids cannot.
d) only gases and liquids can be compressed.

3. When 100 mL of water in a beaker boils it:

a) forms a liquid.
b) changes to a solid
c) turns to a gas.
d) changes its chemical properties.

4. A liquid takes the shape of the container because its particles are:

a) very small and sink to the bottom.
b) in fixed position.
c) very close together.
d) able to move past each other.

5. Evaporation and condensation :

a) occur at certain temperatures.
b) are changes that happen to water only.
c) are caused when substances are heated.
d) are changes of state.

6. Matter that is composed of only one type of atom is called:

a) an element.
b) a compound.
c) a molecule.
d) a mixture.

7. Iron is difficult to compress because:

a) the particles that make up iron are very hard.
b) the particles that make up iron are very close together.
c) iron is very heavy.
d) iron conducts electricity.

8. Solids usually expand when heated because.

a) the movement of the molecules differs from the movement in a gas or a liquid.
b) the molecules expand.
c) the molecules vibrate more rapidly and need more room.
d) they burn or melt.

9. A balloon is blown up and fastened with a string, tightly (Figure 1). The balloon is put into a freezer for a short time and after that figure 2 was obtained.

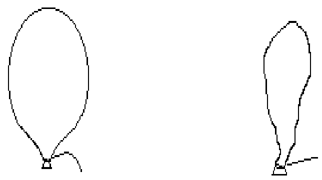


Figure 1   Figure 2

a) some molecules contract.
b) the molecules cool down.
c) changes its chemical properties.
d) the molecules leak out.

10. When water evaporates it:

a) changes to a liquid.
b) forms a solid.
c) turns to a gas.
d) goes from solid to a liquid.

11. Methylated spirits on your arm feels cool because:

a) it evaporates causing cooling.
b) all wet things are normally cold.
c) It condenses to a liquid.
d) It dries the sweat from your skin.

End of test

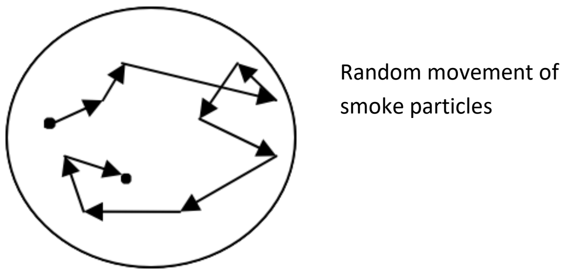
Appendix C
The Particle Theory Diagnostic Instrument
Year 8

Direction

- Read the items carefully and take time to consider your answer.
- Record the answers on the answer sheet provided.
- To register a response completely fills the bubble ~ with a **blue** or **black** ballpoint pen.
- Completely fill a single bubble corresponding to your answers and reasons given on the test.
- If you make an error, cross out the unwanted response ~ and completely fill the circle corresponding to your wanted response.
- If you choose “other reason” please write your reason to the right of this question on this sheet.

Item 1

The diagram represents the random zigzag movement of smoke particles (referred to as Brownian motion) when smoke in a glass container is viewed under a microscope.



What conclusion can you make from this observation?
A Smoke particles are floating in air.
B Air consists mainly of empty space
C Air is made up of tiny particles moving randomly.
D Smoke particles are larger than air particles.

The reason for my choice of answer is:

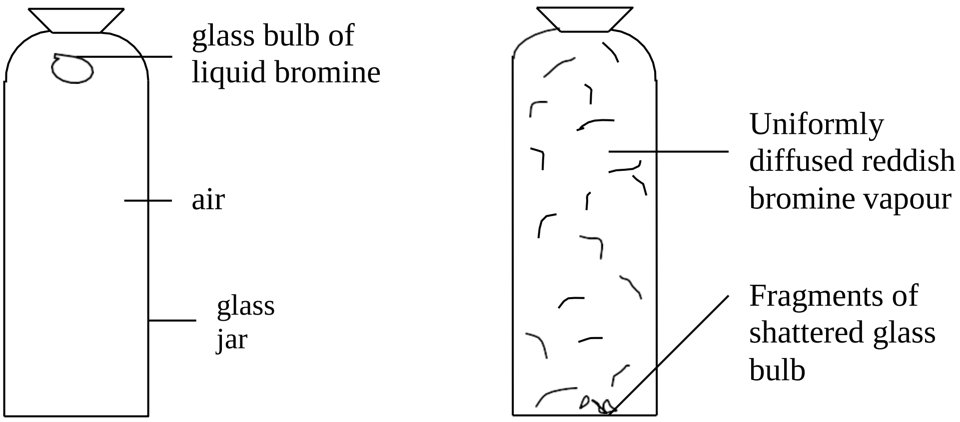
1 Smoke particles are large.
2 There are large spaces between the smoke particles.
3 Colliding smoke particles move in a random zigzag manner.
4 Air particles are constantly colliding with smoke particles.
5 *Other reason*:………………………………………………………………………

………………………………………………………………………………………..

Item 2

A small glass bulb containing liquid bromine was dropped into a tall jar of air and the jar was immediately stoppered. The bulb shattered on hitting the bottom of the jar, releasing bromine vapour. After several hours, reddish bromine vapour had diffused uniformly throughout the jar.

If the experiment is repeated after pumping out most of the air from the jar, we would expect the reddish bromine vapour to diffuse and fill the jar within a few seconds.



A True

B False

The reason for my choice of answer is:

1 The heavier bromine molecules will sink to the bottom of the jar.
2 Fewer collisions occur between the bromine molecules in the absence of air particles.
3 Bromine molecules can now occupy the extra space that was previously taken up by the air particles.
4 Bromine molecules diffuse slowly in a random zigzag manner to fill the jar.
5 Bromine diffuses faster because fewer collisions occur between bromine and air particles.
6 *Other reason*:…………………………………………………………………………

………………………………………………………………………………………..

Item 3

When orange juice from a soft drink can is poured into a tall narrow glass, the volume of the liquid remains the same.

A True B False

The reason for my choice of answer is:

1 The particles are able to move about freely.
2 The particles are able to move within a fixed volume.
3 Some of the particles may have escaped as the liquid evaporated.
4 *Other reason*:………………………………………………………………………

………………………………………………………………………………………..

Item 4

The diagram shows a coloured gas being compressed in a gas syringe until the plunger could not be pushed any further. The experiment was repeated using the same volume of a coloured liquid.

It was found that the final volume of the gas was
A much less than that of the liquid.
B much greater than that of the liquid.

The reason for my choice of answer is:

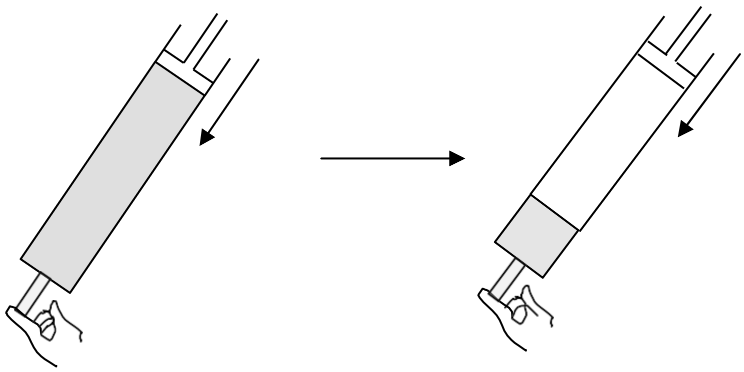
1 The particles in the gas are more widely spaced.
2 The particles in the gas move more freely.
3 The particles in the gas move randomly in all directions.

4 *Other reason*:………………………………………………………………………

………………………………………………………………………………………..

Item 5

The diagram shows a syringe containing a fixed mass of a coloured gas that is compressed by pushing the plunger down.



We can conclude that

A the volume and mass of gas have decreased.
B the volume of gas has decreased while the mass has increased.
C the volume of gas has decreased while the mass remains constant.

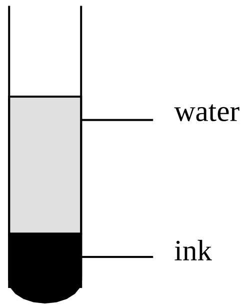
The reason for my choice of answer is:

1 Gas particles can be readily compressed and pushed closer together.
2 The widely-spaced gas particles have been pushed closer together.
3 The number of gas particles has decreased.
4 *Other reason*:…………………………………………………………………

………………………………………………………………………………..

Item 6

A small amount of blue ink was carefully placed at the bottom of a test-tube containing some water as shown in the diagram.



test-tube containing separate ink
and water layers

After several hours, the ink would have diffused throughout the water producing a uniformly blue solution.

A True B False

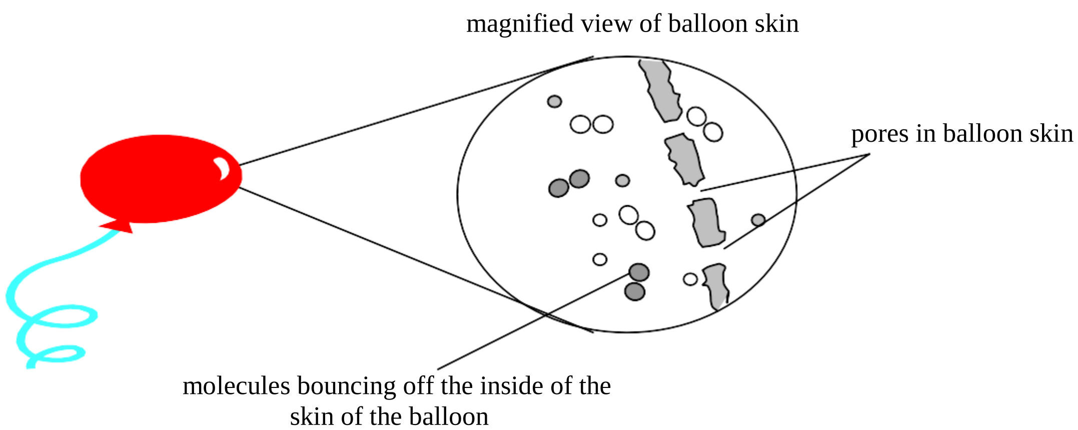
The reason for my choice of answer is:

1 Ink particles readily dissolve in water.
2 The heavier ink particles sink to the bottom of the test-tube.
3 The particles of ink are in constant random motion.
4 Ink and water particles do not mix.
5 *Other reason*:…………………………………………………………………………

………………………………………………………………………………………..

Item 7

A balloon is inflated and tied at the neck to prevent it from deflating.
The diagram shows a magnified view of the skin of the balloon and the particles in the inflated balloon.



After several hours, the balloon would be found to remain the same size.

A True B False

The reason for my choice of answer is:

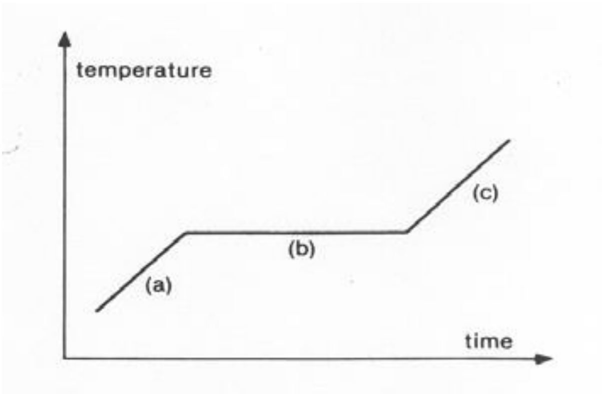
1 Air molecules bounce off the skin of the balloon.
2 Air molecules diffuse through the skin of the balloon.
3 Air molecules are smaller than the holes in the balloon skin.
4 Air molecules from the outside enter the balloon through the pores.

5 *Other reason*:…………………………………………………………………………

…………………………………………………………………………………………..

Item 8

The diagram shows how the temperature changes when a solid like naphthalene is heated gently until it melts. In which section of the curve is the heat energy that is absorbed not heating up the naphthalene?



A (a) B (b) C (c)

The reason for my choice of answer is:

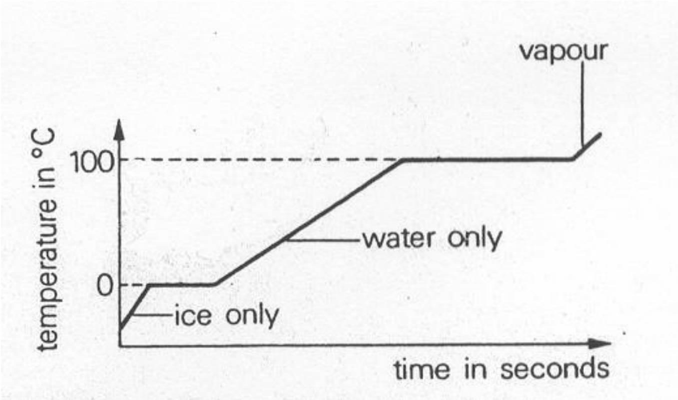
1 The energy absorbed is used to break the bonds in the naphthalene molecules.
2 The heat energy absorbed is used to weaken the intermolecular forces.
3 Heat energy is absorbed to increase the kinetic energy of the molecules.

4 *Other reason*:…………………………………………………………………………

……………………………………………………………………………………..

Item 9

The diagram shows how the temperature changes when some ice at a temperature below 0^oC is heated to above 100^oC.



We may deduce that that liquid water cannot exist at its boiling point of 100^oC.

A True B False

The reason for my choice of answer is:

1 It takes time for the water to boil and change the molecules completely into steam.
2 The molecules do not have sufficient energy to change completely into steam.
3 The attractive forces between all the water molecules have to be weakened.

4 *Other reason*:……………………………………………………………………………

………………………………………………………………………………………..

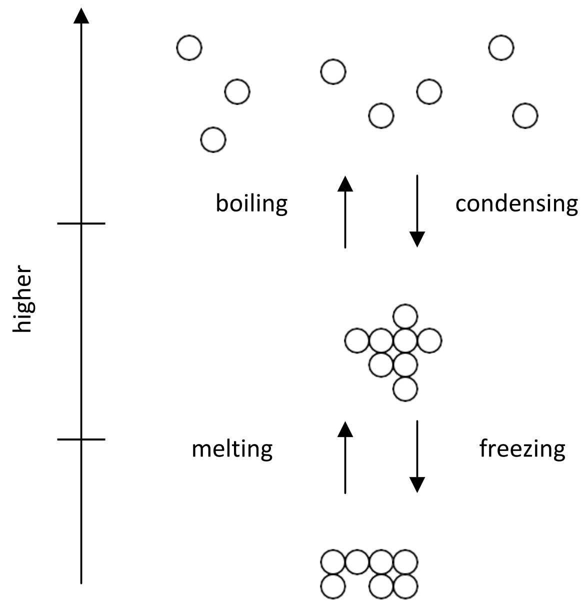
Item 10

The diagram shows the arrangement of particles in different states of matter.

In which of the changes of state will heat energy be absorbed?

A solid → liquid → gas

B gas → liquid → solid



The reason for my choice of answer is:

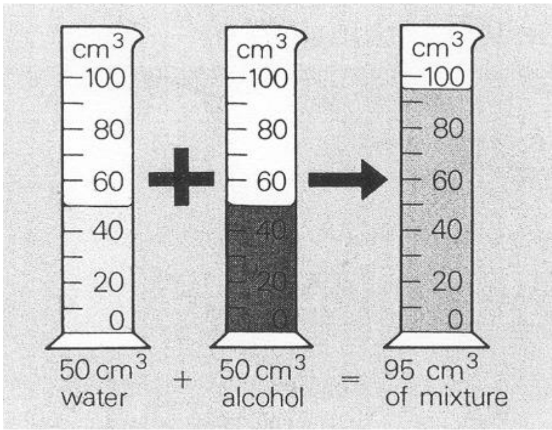
1 The H_2O molecules are moved further away from each other.
2 The bonds in the H_2O molecules are broken.
3 The attractive forces between the H_2O molecules are weakened.

4 *Other reason*:…………………………………………………………………………

…………………………………………………………………………………………..

Item 11

The diagram shows that the total volume of liquid decreases when water and alcohol are mixed together.



We can conclude that some of the alcohol has evaporated.

A True B False

The reason for my choice of answer is:

1 The molecules of the two liquids occupy the spaces between each other.
2 The alcohol molecules have dissolved in water.
3 Some alcohol has evaporated as a result of collisions between the molecules.
4 Molecules of the two liquids have mixed together.

5 *Other reason*:……………………………………………………………………

……………………………………………………………………………………..

The End

Appendix C
Acid and Base Diagnostic test
Chemistry Year 11

Directions

- There are 25 multiple choice questions in this test.
- Read each question and answer choice carefully and choose the ONE best answer.

1. Which of the following statements is true concerning acids and bases?

   A acids and bases don't react with each other
   B acids mixed with bases neutralize each other
   C acids mixed with bases make stronger bases
   D acids mixed with bases make stronger acids

2. True or false: bases are sometimes called alkalis.

   A true
   B false

3. Which is the correct set of acid properties

   A. sour taste, corrosive, change litmus from red to blue
   B sour taste, corrosive, change litmus from blue to red
   C sweet taste, slippery, change litmus from blue to red
   D sour taste, slippery, change litmus from blue to red

4. Neutral solutions have a pH of:

   A 0
   B 7
   C 14

5. An amphoteric substance can act as both an acid and a base. True or false?

   A true
   B false

6. Which substance completely dissociates in water?

   A weak acids
   B strong acids

7. A chemical species having one ionizable hydrogen ion is:

A monoprotic
B diprotic
C triprotic
D polyprotic

8. Vinegar, fruit juice, and cola are examples of:

A strong acids
B weak acids
C strong bases
D weak bases

9. Which, if any, of the following acids is strong?

A phosphoric
B carbonic
C acetic
D water
E none of the above

10. Which one of the following is a strong acid?

A H_2CO_3
B H_2SO_3
C H_2SO_4
D H_3PO_4
E CH_3COOH

11. The substance NH_3 is considered

A a weak acid
B a weak base
C a strong acid
D a strong base

12. The substance $HClO_4$ is considered

A a weak acid
B a weak base
C a strong acid
D a strong base

13. Select the correct set of products for the following reaction.

$$Ba(OH)_2\ (aq) + HNO_3\ (aq)$$

A BaN_2 (s) + H_2O (l)
B $Ba(NO_3)_2$ (aq) + H_2O (l)
C Ba (s) + H_2(g) + NO_2(g)
D No reaction occurs

14. In a neutralization reaction the indicator will change color.

A True
B False

15. All acid base reactions produce a salt and water as the only products.

A True
B False

16. Acids react with carbonates to produce;

A carbon dioxide, salt and water
B hydrogen and water
C hydrogen and salt
D no reaction

17. Acids have pH

A below 7
B above 7

18. Acids change litmus paper to red.

A True
B False

19. The acid used in car battery is

A hydrochloric acid
B sulfuric acid
C acetic acid
D phosphoric acid

20. Bases taste-

A sweet
B bitter
C sour
D tasteless

21. Which of the following substances contain acid?

A An orange
B Bleach
C Distilled water
D Washing powder

22. Which of the following substances contain an alkali?

A Baking powder
B Coca cola
C Distilled water
D Vinegar

23. Which of the following pH numbers indicates a strong acid?

A 1
B 5
C 7
D 14

24. Which of the following pH numbers indicate a strong alkali?

A 1
B 5
C 9
D 14

25. Strong acids and strong alkalis are.......

A Able to turn blue litmus paper red
B Corrosive and/or caustic
C Sour
D Sweet

End of test

Appendix C
ACID-BASE REACTIONS CONCEPT INVENTORY (ABCI)
Year 11 Chemistry

Directions:

- On the answer sheet provided for each question (1 – 11) choose:
- one BEST answer (Y or N).
- one GOOD reason (A – D).
- your CONFIDENCE (0% – 100%).

1) Is this an acid-base reaction?

$$H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$$

Y) Yes

N) No

I chose my answer to question 1 because __________________.

A) NaOH did not become NaO^- or $NaOH_2^+$. It changed into Na_2SO_4

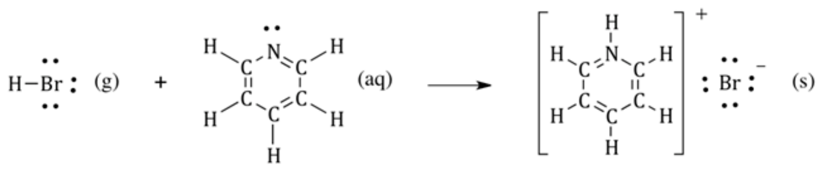
B) H^+ and OH^- combined

C) Na_2SO_4 is a base and H_2O is an acid

D) there is not an equilibrium arrow

How confident are you with the answer and reason you chose? (0-100%)

2) Is this an acid-base reaction?



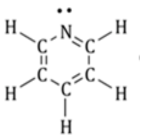
Y) Yes

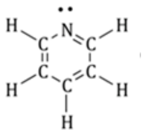
N) No

I chose my answer to question 2 because ________________.

A) there is only one product. There is no conjugate acid or conjugate base

B) HBr is a gas

C)  is not a base

D)  donates an electron pair to H^+

How confident are you with the answer and reason you chose? (0-100%)

3) Is this an acid-base reaction?

$$Zn(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$$

Y) Yes

N) No

I chose my answer to question 3 because ________________.

A) a proton is donated and accepted

B) in the reverse direction, H_2 can donate a proton to $ZnCl_2$

C) one electron is transferred to H^+

D) Cl^- donates an electron pair to Zn

How confident are you with the answer and reason you chose? (0-100%)

4) Is this an acid-base reaction?

$$HNO_3\,(aq) + NH_3\,(aq) \longrightarrow NH_4NO_3\,(aq)$$

Y) Yes

N) No

I chose my answer to question 4 because ___________________.

A) HNO_3 bonds to NH_3 to form one product

B) there is only one product. There is no conjugate acid or conjugate base

C) a proton is donated and accepted

D) the product will dissociate into spectator ions

How confident are you with the answer and reason you chose? (0-100%)

5) Is this an acid-base reaction?

$$CH_4\,(g) + 2O_2\,(g) \longrightarrow CO_2\,(g) + 2H_2O(g)$$

Y) Yes

N) No

I chose my answer to question 5 because ___________________.

A) CH_4 donates a proton to O_2

B) CH_4 is oxidized

C) the reactants are gases

D) water is produced

How confident are you with the answer and reason you chose? (0-100%)

6) Is this an acid-base reaction?

$$CoCl_2\,(aq) + Na_2CO_3\,(aq) \longrightarrow 2NaCl(aq) + CoCO_3\,(s)$$

Y) Yes

N) No

I chose my answer to question 6 because __________________.

A) a solid is formed

B) CO_3^{2-} donates an electron pair to Co^{2+}

C) NaCl is produced

D) an electron pair is not donated

How confident are you with the answer and reason you chose? (0-100%)

7) Is this an acid-base reaction?

Y) Yes

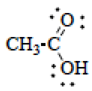
N) No

I chose my answer to question 7 because __________________.

A) the cations and anions switch places

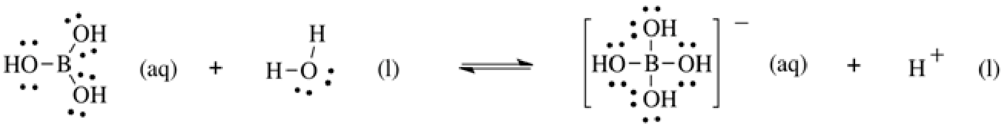
B) a proton and hydroxide combine to produce water

C) both reactants have hydroxide present

D) Hydrogen from CH_3 in  is transferred to NaOH

How confident are you with the answer and reason you chose? (0-100%)

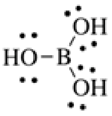
8) Is this an acid-base reaction?



Y) Yes

N) No

I chose my answer to question 8 because __________________.

A)  has three OH groups

B) water is neutral

C) an electron pair is donated

D) in the reverse direction, a proton is donated

How confident are you with the answer and reason you chose? (0-100%)

9) Is this an acid-base reaction?

$$HCN(aq) + H_2O(l) \longrightarrow H_3O^+(aq) + CN^-(aq)$$

Y) Yes

N) No

I chose my answer to question 9 because __________________.

A) water is neutral

B) there are no acids or bases in the reactants and products

C) H_2O is an acid because it accepts a proton to become H_3O^+, **and**

HCN is a base because it donates a proton to become CN^-

D) H_2O is a base because it accepts a proton to become H_3O^+, **and**

HCN is an acid because it donates a proton to become CN^-

How confident are you with the answer and reason you chose? (0-100%)

10) Is this an acid-base reaction?

$$KOH(aq) + HNO_3(aq) \longrightarrow KNO_3(aq) + H_2O(l)$$

Y) Yes

N) No

I chose my answer to question 10 because HNO_3^- and KOH _________________, and H^+ and OH^- _________________, and K^+ and NO _________________.

A) …. dissociate ….combine to form water ….combine to form bonds
B) …. dissociate ….remain in solution as ions ….remain in solution as ions
C) …. dissociate ….combine to form water ….remain in solution as ions
D) HNO_3 and KOH do not dissociate. They switch cations.

How confident are you with the answer and reason you chose? (0-100%)

11) Is this an acid-base reaction?

$$HCl(aq) + NH_3(aq) \longrightarrow NH_4Cl(aq)$$

Y) Yes

N) No

I chose my answer to question 11 because _________________.

A) HCl dissociates **and** a proton transfers

B) HCl and NH_3 dissociate **and** H^+, Cl^-, N^{3+}, and $3H^-$ recombine to neutralize charge

C) HCl and NH_3 dissociate **and** H^+, Cl^-, N^{3+}, and $3H^-$ stay in solution as spectator ions

D) HCl and NH_3 do not dissociate. They combine to form a new compound

How confident are you with the answer and reason you chose? (0-100%)

END OF INVENTORY

Appendix D

Surveys

Appendix D
Attitude towards Chemistry Inventory (ASCI)
College and University Classroom Environment Inventory (CUCEI)

Participant Information Sheet

Curtin University

Project Title: **Process Oriented Guided Inquiry Learning in Australian secondary science classrooms: a model pedagogy to develop science inquiry skills.**

Researcher's name: Aneeta Dogra **Supervisor's name**: Dr. Daniel Southam

Invitation to participate

You are kindly invited to participate in this research project. Participation is voluntary and you are free to withdraw from the questionnaire at any time without affecting your status now or in the near future.

The purpose of the research project

This project aims to develop and adapt learning objects for use in Australian secondary classes. The effectiveness of POGIL on students learning outcomes and science inquiry skills will be the focus of this research study.

What participants are expected to do

Your participation involves answering questions regarding your science classes. The survey should take less than 15 minutes to complete. There are no known or anticipated risks to participation in this study.

Data collection

Your confidentiality will be protected at all times. The researcher will take every care to remove responses from any identifying material as early as possible. The information will be kept in a locked cabinet for at least five years, before a decision is made as to whether it should be destroyed.

Your contribution

POGIL is a student centered inquiry based method which helps students to develop their critical thinking and communication skills as well as keeping them actively engaged in the learning process. Your assistance would be of immense value to this research project.

Contact information

Should you have any ethical concerns regarding this research project, please contact Dr. Daniel Southam on 9266 2380 or email D.Southam@curtin.edu.au .

Thank you for your cooperation.

This study has been approved by the Curtin University Human Research Ethics Committee (Approval Number HR-RD-56-12). If needed, verification of approval can be obtained either by writing to the Curtin University Human Research Ethics Committee, c/- Office of Research and Development, Curtin University, GPO Box U1987, Perth, 6845 or by telephoning +61-(0)8-9266-2784 or hrec@curtin.edu.au

Instructions

This survey has two parts on three pages. Please read the instructions with each part and completely fill the bubble ~ with a blue or black ballpoint pen. Read all instructions carefully. If you make an errorr, cross out the unwanted response ✗ and completely fill the circle corresponding to your wanted response. Do not make any other stray marks on the page.

Part 1(ASCI Survey)

A list of opposing words appears below. Rate how well these words describe your feelings about **science**. Think carefully and **try not to include** your feelings toward science teachers or science classes.

For each line, choose a position between the two words that describes **exactly how you feel**. Mark that number here by shading a single bubble. The middle position is if you are undecided or have no feelings related to the terms on that line.

SCIENCE IS

	1	2	3	4 middle	5	6	7	
easy	□	□	□	□	□	□	□	hard
Complicated	□	□	□	□	□	□	□	simple
Confusing	□	□	□	□	□	□	□	clear
Comfortable	□	□	□	□	□	□	□	uncomfortable
satisfying	□	□	□	□	□	□	□	frustrating
challenging	□	□	□	□	□	□	□	not challenging
pleasant	□	□	□	□	□	□	□	unpleasant
chaotic	□	□	□	□	□	□	□	organised
				middle				

Part 2(CUCEI Survey)

The purpose of this part of the questionnaire is to find out your opinions about the class you are attending right **now**. This questionnaire is designed for use in gathering opinions about the practices in this class.

This form of the questionnaire assesses your opinion about what this class is ***actually like***. Indicate your opinion about each questionnaire statement by filling in the circle:

1. if you **STRONGLY AGREE** that it describes what this class is actually like.
2. if you **AGREE** that it describes what this class is actually like.
3. if you are **NEUTRAL** that it describes what this class is actually like.
4. if you **DISAGREE** that it describes what this class is actually like.
5. if you **STRONGLY DISAGREE** that it describes what this class is actually like..

Remember that you are describing your ***actual*** classroom.

	Strongly Disagree	Disagre	Neutral	Agree	Strongly Agree
1. The teacher considers students' feelings.	1	2	3	4	5
2. The teacher talks rather than listens.	1	2	3	4	5
3. The class is made up of individuals who don't know each other well.	1	2	3	4	5
4. The students look forward to coming to classes.	1	2	3	4	5
5. Students know exactly what has to be done in our class.	1	2	3	4	5
6. New ideas are seldom tried out in this class.	1	2	3	4	5
7. All students in the class are expected to do the same work, in the same way and in the same time.	1	2	3	4	5
8. The teacher talks individually with students.	1	2	3	4	5
9. Students put effort into what they do in classes.	1	2	3	4	5
10. Each student knows the other members of the class by their first names.	1	2	3	4	5
11. Students are dissatisfied with what is done in the class.	1	2	3	4	5
12. Getting a certain amount of work done is important in this class.	1	2	3	4	5
13. New and different ways of teaching are seldom used in this class.	1	2	3	4	5
14. Students are generally allowed to work at their own pace.	1	2	3	4	5
15. The teacher goes out of his/her way to help students.	1	2	3	4	5
16. Students 'clock watch' in this class.	1	2	3	4	5
17. Friendships are made among students in this class.	1	2	3	4	5
18. After the class, the students have a sense of satisfaction.	1	2	3	4	5
19. The group often gets sidetracked instead of sticking to the point.	1	2	3	4	5
20. The teacher thinks up innovative activities for students to do.	1	2	3	4	5
21. Students have a say in how class time is spent.	1	2	3	4	5
22. The teacher helps each student who is having trouble with the work.	1	2	3	4	5
23. Students in this class pay attention to what others are saying.	1	2	3	4	5
24. Students don't have much chance to get to know each other in this class.	1	2	3	4	5
25. Classes are a waste of time.	1	2	3	4	5
26. This is a disorganised class.	1	2	3	4	5
27. Teaching approaches in this class are characterised by innovation & variety.	1	2	3	4	5
28. Students are allowed to choose activities and how they will work.	1	2	3	4	5

Please turn over and complete the questions on the last page.

Remember that you are describing your ***actual*** classroom.

	Strongly Disagree	Disagre	Neutral	Agree	Strongly Agree
29. The teacher seldom moves around the classroom to talk with students.	1	2	3	4	5
30. Students seldom present their work to the class.	1	2	3	4	5
31. It takes a long time to get to know everybody by his/her first name in this class.	1	2	3	4	5
32. Classes are boring.	1	2	3	4	5
33. Class assignments are clear so everyone knows what to do.	1	2	3	4	5
34. The seating in this class is arranged in the same way each week.	1	2	3	4	5
35. Teaching approaches allow students to proceed at their own pace.	1	2	3	4	5
36. The teacher isn't interested in students' problems.	1	2	3	4	5
37. There are opportunities for students to express opinions in this class.	1	2	3	4	5
38. Students in this class get to know each other well.	1	2	3	4	5
39. Students enjoy going to this class.	1	2	3	4	5
40. This class seldom starts on time.	1	2	3	4	5
41. The teacher often thinks of unusual class activities.	1	2	3	4	5
42. There is little opportunity for a student to pursue his/her particular interest in this class.	1	2	3	4	5
43. The teacher is unfriendly and inconsiderate towards students.	1	2	3	4	5
44. The teacher dominates class discussions.	1	2	3	4	5
45. Students in this class aren't very interested in getting to know other students.	1	2	3	4	5
46. Classes are interesting.	1	2	3	4	5
47. Activities in this class are clearly and carefully planned.	1	2	3	4	5
48. Students seem to do the same type of activities every class.	1	2	3	4	5
49. It is the teacher who decides what will be done in our class.	1	2	3	4	5

Thank you for participating in this survey.

Appendix D
Attitude towards Chemistry Inventory (ASCI)
Science Laboratory Environment Inventory-preferred (SLEI)

Participant Information Sheet

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SCIENCE IS

	1	2	3	4 middle	5	6	7	
easy	☐	☐	☐	☐	☐	☐	☐	hard
Complicated	☐	☐	☐	☐	☐	☐	☐	simple
Confusing	☐	☐	☐	☐	☐	☐	☐	clear
Comfortable	☐	☐	☐	☐	☐	☐	☐	uncomfortable
satisfying	☐	☐	☐	☐	☐	☐	☐	frustrating
challenging	☐	☐	☐	☐	☐	☐	☐	not challenging
pleasant	☐	☐	☐	☐	☐	☐	☐	unpleasant
chaotic	☐	☐	☐	☐	☐	☐	☐	organised
				middle				

Part 2(SLEI Preferred Survey)

This questionnaire contains statements about practices which could take place in this laboratory class. You will be asked **how often** you would **prefer** each practice to take place.

There are no ‘right’ or ‘wrong’ answers. Your opinion is what is wanted.

Think about how well each statement describes what your preferred science class is like. Fill in the circle containing

1. if you would prefer the practice to take place ALMOST NEVER
2. if you would prefer the practice to take place SELDOM
3. if you would prefer the practice to take place SOMETIMES
4. if you would prefer the practice to take place OFTEN
5. if you would prefer the practice to take place VERY OFTEN

Be sure to give an answer for all questions. If you change your mind about an answer, just cross it out and fill in another circle.

Some statements in this questionnaire are fairly similar to other statements. Don’t worry about this. Simply give your opinion about all statements.

Practice Example. Suppose that you were given the statement: “I would choose my partners for activities.” You would need to decide whether you thought that you would **prefer** to choose your partners *Almost Never*, *Seldom*, *Sometimes*, *Often* or *Very Often*. For example, if you selected *Very Often*, you would fill in the circle around number 5 on your Answer Sheet.

Remember that you are describing your ***preferred*** classroom.	Almost Never	Seldom	Sometimes	Often	Very Often
1. I would on well with students in this science class	1	2	3	4	5
2. There would opportunity for me to pursue my own science interests in this classroom.	1	2	3	4	5
3. What I do in our regular science class would be unrelated to my activities.	1	2	3	4	5
4. My science class would have clear rules to guide my activities.	1	2	3	4	5
5. I would find science activities very challenging.	1	2	3	4	5
6. I would have little chance to get to know other students in this science class.	1	2	3	4	5
7. In this science class, I would be required to plan my own steps to solve a given problem.	1	2	3	4	5
8. The activities would be unrelated to the topics that I am studying in my science class.	1	2	3	4	5
9. My science classroom would be rather informal and few rules are imposed on me.	1	2	3	4	5
10. The resources that I need for activities would be readily available.	1	2	3	4	5
11. Members of this science class would help me.	1	2	3	4	5
12. Members of our group would work on different parts of the same problem.	1	2	3	4	5
13. My regular science class work would be integrated with activities.	1	2	3	4	5
14. I would be required to follow certain rules in the science classroom	1	2	3	4	5
15. I would find very hard to understand the science activities	1	2	3	4	5
16. I would get to know students in this science class well	1	2	3	4	5
17. I would be apply knowledge to new situations	1	2	3	4	5
18. I would use the concepts from my regular science class sessions during activities	1	2	3	4	5
19. There would be a recognised way for me to do things safely in this classroom.	1	2	3	4	5
20. There would be insufficient information in the science activities to answer the questions.	1	2	3	4	5

Please turn over and complete the questions on the last page.

Remember that you are describing your ***preferred*** classroom.

	Item	Almost Never	Seldom	Sometimes	Often	Very Often
21.	I would be able to depend on other students for help in this science class	1	2	3	4	5
22.	In my science classes, I would do different activities than some of the other students.	1	2	3	4	5
23.	The topics covered in regular science class work would be quite different from topics with which I deal in activities.	1	2	3	4	5
24.	There would be few fixed rules for me to follow during activity sessions.	1	2	3	4	5
25.	I would find that the science activities are very boring.	1	2	3	4	5
26.	It would take me long time to get to know everybody by his/her first name.	1	2	3	4	5
27.	In my activity sessions, the teacher would decide the best way for me to carry out the activity.	1	2	3	4	5
28.	What I do in the activity sessions would help me to understand the science.	1	2	3	4	5
29.	My science classroom would be rather informal and few rules are imposed on me.	1	2	3	4	5
30.	I would be fully engaged while doing science activities.	1	2	3	4	5
31.	I would work cooperatively in activity sessions.	1	2	3	4	5
32.	I would decide the best way to proceed during activity sessions.	1	2	3	4	5
33.	My activity work and regular class work would be unrelated.	1	2	3	4	5
34.	My science class would run under clearer rules than my other classes.	1	2	3	4	5
35.	My science classroom would have enough room for individual or group work.	1	2	3	4	5

Thank you for participating in this survey.

Appendix D INTERVIEW PLAN

I) Interview Protocol

Students will be asked to fill out a permission form.

II) Interview

A. **Introduction of interviewer**

Hello, my name is ____________________, and I have been asked to interview _____________________. During the interview, I would like to discuss the following topic: The effectiveness of POGIL in students understanding of Chemistry.

B. **Group work**

1. Describe your personal experience about working in groups (collaborative learning) on the POGIL worksheets?
2. Do you enjoy collaborative inquiry based learning? (probing question)
3. How did working in groups affect your understanding of the concept being studied?
4. Has your understanding of Chemistry increased by collaborative learning? Explain how working in groups benefited you? (probing question)

C. **POGIL worksheets**

5. Here is an example of an activity sheet you have already completed. What reasons would you use for answering this key question?
6. What reasons would you use for not answering this key question?
7. Do you find pictures and graphs useful for answering the problem solving key questions?
8. How do rate your problem solving ability?
9. What are the benefits of having key questions on the worksheet?

D. **General**

10. How did you find the POGIL worksheets (easy/ challenging)?
11. How do you compare teacher centred teaching as compare to POGIL?
12. Do you have any recommendations to make this process more beneficial?

Appendix D

Strengths, areas for Improvement, and Insights (SII) reflection sheet

Thank you for taking time to answer these questions. This questionnaire is part of a study about the impact of the use POGIL activities in the teaching and learning chemistry. The responses are treated as confidential and would only be used for research purposes.

Circle the focus of today's lesson.

Team work	POGIL pedagogy	POGIL worksheets	POGIL environment	Management	Problem solving	Communication

1. Write a Strength about today's' focus and explain why it is a strength?

2. Write an area of Improvement and how it can be improved?

3. Write down any Insight (new understanding) you have had gained today.

Collaborative learning

Today your group worked collaboratively on this activity. On a scale of 1 to 5 circle how does your group worked on this activity.

☹☹	☹	😐	☺	☺☺
VERY BAD	**BAD**	**OK**	**GOOD**	**VERY GOOD**

Appendix D
Observation note sheet

Classroom Observation sheet	
Date of observation:	
Year level:	Subject:
Period:	Room:
Lesson topic:	
Observation	Reflections

Appendix E

Year 8 POGIL worksheets

Appendix E
Year 8 POGIL worksheets
THE MATTER (Activity 1)

Why?

Matter is everything around us. Matter is anything that has mass and takes up space. Everything around us makes up matter. All these things feel, smell, look or taste different from each other. Based on differences in their properties matter can be classified into three categories: solids, liquids & gases. Some common properties are mass, shape, diffusion and compressibility.

Success Criteria

- Understand more about matter
- Demonstrate the difference between solids, liquids and gases
- Comprehend diagrams
- Drawing up table
- Classifying things

Model 1

1. Get a plastic syringe (piston) and fill it with **water**. Now close the opening using a finger and push the plunger down. What happens?

____

2. Can you compress (squeeze) water?

____

3. Now fill the plastic syringe with **air**. Close the opening using a finger and push the plunger down. What happens?

____

4. Can you compress (squeeze) gas?

____

5. Now fill the plastic syringe with **a solid** (for example, salt, sugar or rice). Close the opening using a finger and push the plunger down. What happens?

____

6. Can you compress (squeeze) gas?

____

Compression means decrease in volume of an object or a substance resulting from applied force or pressure.

7. Without breaking the wooden block can you change its shape?

8. Pour some water in a beaker and some in a conical flask. Does water has a definite or fixed shape?

9. Think about party balloons. What is inside the balloons?

10. What happens to the party balloons after a day?

11. Did the size of the balloon increase or decrease?

12. Do all balloons have same or fixed shape?

Shape means the external appearance of a substance.

13. Your teacher will open a scent bottle in one corner of the room. Can you smell it at the other end?

14. Get some hot water and some cold water in two beakers and put a drop of coloured dye into each beaker. Observe what happens?

15. Your teacher will put a soap bar on a table. Smell it from a distance. Can you smell the soap bar from a distance?

16. Now go closer to soap bar. Can you smell it now?

The spreading of particles is called diffusion.

17. Out of soap bar smell, scent bottle smell and coloured dye, which spreads further? Put them in order of most to the least.

KEY QUESTIONS

1. By using the above information complete the following table.

PROPERTIES	SOLIDS	LIQUIDS	GASES
Takes up space		YES	
Has mass			YES
Has definite (fixed) shape	YES		NO
Has fixed volume			
Can diffuse			
Can be compressed (squeezed)	NO		

2. Unjumble the following sentences and write them again in the space provided.

a) Space take matter and mass has up.

____

b) Matter properties are used to describe.

____

c) Solids the states of liquids and matter are gases.

____

d) Solids fixed a shape have.

____

e) Compressed gases can be easily.

____

f) Quickly diffuse gases than more liquids.

____

g) Shape the container liquids of take their.

____

3. What are **three properties** that juice, petrol and milk have in common?

1.____

2.____

3.____

4. Prepare a list of **THREE different substances** around your classroom and classify them as solids, liquids or gases. List the properties of each substance also. An example has been done for you.

SUBSTANCE	SOLID/LIQUID/GAS	PROPERTIES
Orange juice	liquid	-Can be poured - takes up containers shape -has mass and takes up space -diffuse slowly -incompressible

Appendix E
Year 8 POGIL worksheets
THE PARTICLE THEORY (Activity 2)

Why?

Solids, liquids and gases are made up of very small particles. To understand why solids, liquids and gases behave differently scientists developed a theory called particle theory of matter. It is also called as kinetic theory of matter. The word 'kinetic' comes from Greek and means movement or motion.

Success criteria

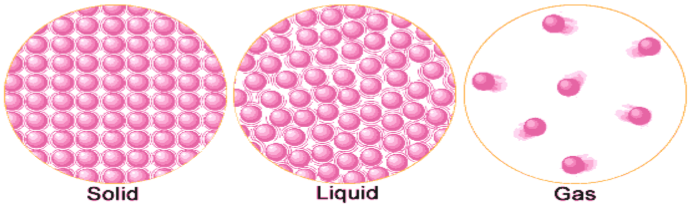
- Comprehending diagrams and written information.
- Understand kinetic theory of matter.
- Understand more about states of matter.
- Applying theory to everyday situation.

Prerequisites

- Different states of matter

Model 1- kinetic theory

Here are three pictures showing a microscopic view of a solid, liquid and gas.



Note- each circle represents a particle

The kinetic theory (particle theory) explains why solids, liquids and gases behave differently. The main points of kinetic theory are:

1. ***All matter is made up of small particles.***
2. ***These particles are always moving.***
   - ***When a substance is heated, its particles move faster and they need more room.***
   - ***When a substance is cooled, its particles move slowly and they need less room.***
3. ***The particles are held together by forces which vary (differ) in strength.***

In solids particles are very closely packed and are held together by strong forces. The particles are not free to move. They can only vibrate in fixed positions.

In liquids particles are as close together as they can be. These particles are held together by forces which are not as strong as in solids. The particles can roll over one another.

In gases particles are far apart from each other. The particles are not held together by forces and are free to move.

Key questions

1. Look at the picture of a solid, liquid and gas in model 1.

a) What do you notice about the arrangement of particles in solids?

____

____

b) What do you notice about the arrangement of particles in liquids?

____

____

c) What do you notice about the arrangement of particles in gases?

____

____

2. Which picture has the largest number of particles and which has smallest number of particles?

____

Density is the measure of number of particles in a given space.

3. Which picture appears to have particles with the greatest movement (motion)?

____

4. Using the information provided in model 1 fill in the blanks.

   a) Matter is made up tiny ____________________ which are always__________________.

   b) The particles move ____________in hot substances than in cold substances.

   c) When matter is ___________ the particles move more slowly.

   d) The particles in matter are held together by ______________ which vary in ____________.

   e) Solids and liquids cannot be compressed because their particles are _______________ _______________.

   f) Gases can be compressed very easily because their particles are __________ ___________.

   g) Liquids diffuse ___________ because their particles have ______________ movement.

h) Gases diffuse quickly because their particles are ____________ to _______________.

i) Liquids can be poured because their particles can _____________ ___________ one another.

5. Using the information provided in model 1, complete the following tables. The first one has been done for you.

PROPERTY OF SOLIDS		EXPLANATION USING KINETIC THEORY
1.	have a fixed shape	The particles are not free to move. They can only vibrate in fixed positions.
2.	Cannot be poured	
3.	Do not diffuse	
4.	Cannot be compressed	
5.	Expand very little when heated	

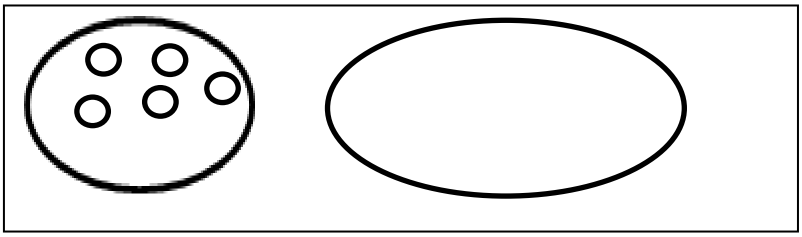
PROPERTY OF LIQUIDS		EXPLANATION USING KINETIC THEORY
1.	Take the shape of their container	
2.	Can be poured	
3.	Diffuse slowly	
4.	Cannot be compressed	
5.	Expand more when heated	

PROPERTY OF GASES		EXPLANATION USING KINETIC THEORY
1.	Take the shape of their container	
2.	Can be poured	
3.	Diffuse very fast	
4.	Can be compressed easily	
5.	Expand a lot when heated	

Critical thinking questions

1. Imagine a balloon that has 5 air molecules. The balloon is heated and it expands. How do you expect the particles to be in the heated balloon?

a) Draw the particles in below figure.



b) Explain why you draw such a picture.

____

____

____

2. A balloon is blown up and fastened with a string, tightly (Figure 1). The balloon is put into a ***freezer*** for a short time and after that figure 2 was obtained. How do you explain this event although balloon does not leak air out?

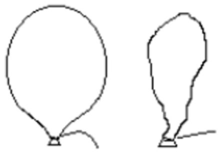


Figure 1 Figure 2

____

____

____

____

3. You can compress a syringe filled with air but not with water. How do you explain the difference in the compressibility of air and water? What would you see at the particle level to explain what is going on?

____

____

____

____

Appendix E
Year 8 POGIL worksheets
CHANGES OF STATE OF MATTER (Activity 3)

Why?

There are three states of matter. Some substances can exist in all three states. Water can be solid (ice), liquid (water) or a gas (water vapour or steam). The state in which water exists depends on how cold or hot its temperature is.

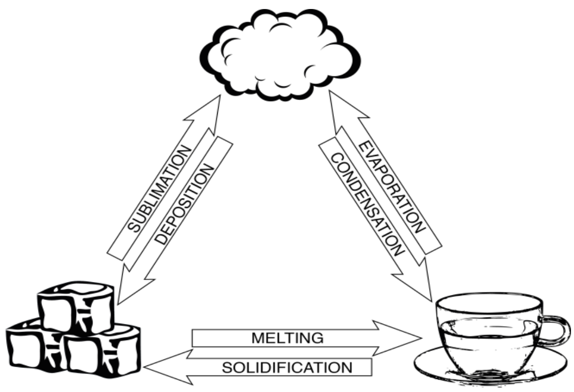
Success criteria

- increase understanding of kinetic theory
- Understanding of different states of matter
- understand that energy involved with the changes of state
- comprehend diagrams
- comprehend information

Prerequisites

- States of matter
- Kinetic theory of matter

Model 1



Key Questions- Using the information provided in model 1, answer the following questions.

1. Name the process by which solids changes into liquids?

____

2. Do we need to supply (add) in heat or take away (remove) heat in the above process?

____

3. Name the process by which liquids changes to gases?

____

4. Do we need to supply (add) in heat or take away (remove) heat in the above process?

____

5. Name the process by which gases change back into liquids?

____

6. Do we need to supply (add) in heat or take away (remove) heat in the above process?

____

7. Name the process by which liquids changes into solids?

____

8. Do we need to supply (add) in heat or take away (remove) heat in the above process?

____

9. Name the process by which solids changes directly into gas?

____

10. Do we need to supply (add) in heat or take away (remove) heat in the above process?

____

Here are some ***Greek*** words. ***endo*** means *in* ***exo*** means *out* ***therm*** means *heat* So, ***endothermic*** means *add heat in* and ***exothermic*** means *take heat out*

11. Is melting an endothermic or an exothermic process? - ____________________________

12. Is evaporation an endothermic or an exothermic process? ________________________

13. Is condensation an endothermic or an exothermic process? ________________________

14. Is solidification an endothermic or an exothermic process? ________________________

15. Is sublimation an endothermic or an exothermic process? ________________________

Model 2 Read the following information.

As solids are heated

- The particles move faster and vigorously.
- They have enough energy to overcome the forces holding them together.
- They start to roll over one another.

- Now the solid starts to melt and becomes liquid.
- The temperature at which solid changes to liquid is called its “melting point”.

As liquids are heated

- The particles roll faster and faster.
- They have enough energy to overcome the forces holding them together.
- They start to break away from each other.
- The particles move freely and liquid now becomes a gas.
- The temperature at which liquid changes to gas is called its “boiling point”.

Key questions

1. What causes the particles of matter to move faster?

   ____

2. Why do particles in a solid eventually break away from their fixed positions when the solid is heated?

   ____

   ____

3. The temperature at which a solid turns to liquid is known as ________________________

4. What do the particles do as a liquid evaporates?

   ____

   ____

5. The temperature at which a liquid turns to gas is known as its ______________________

6. What might happen to the particles of a gas if they slow down enough?

   ____

   ____

7. What might happen to the particles in a liquid before the liquid will freeze?

   ____

   ____

   ____

Critical thinking questions

1. Neena filled a clear glass with some ice water but she forgot to drink it. After a while she realised and came back to drink it. Too her surprise she found many tiny water droplets outside the glass. Explain this phenomenon? (hint look at model 1)

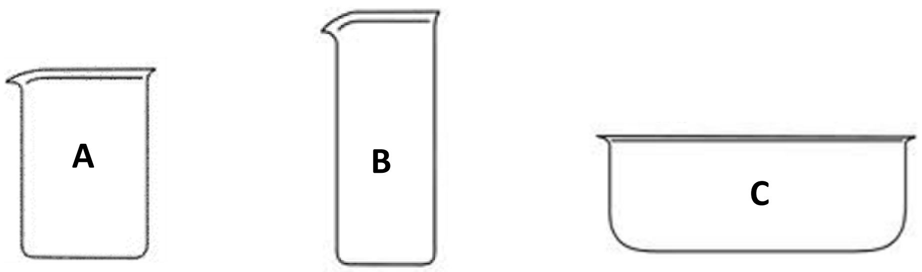
____

____

____

____

2. From which of the containers below would water evaporate :



a) Most quickly and why?

____

____

b) Most slowly and why?

____

____

Appendix E
Year 8 POGIL worksheets
PURE SUBSTANCE OR MIXTURE (Activity 5)

Why?

Scientists have classified matter as solids, liquids and gases. There are other ways to classify matter also such as pure substances or mixtures. All matter can be classified as pure substances or mixtures.

Success Criteria

- Demonstrate the difference between an atoms and a molecules
- Demonstrate the difference between a pure substance and a mixture
- Comprehend diagrams

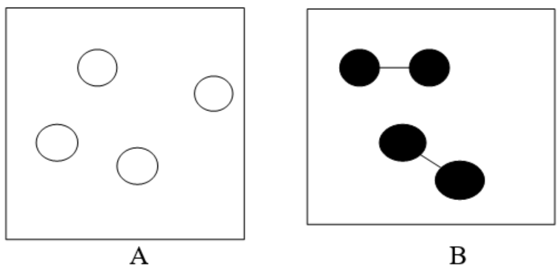
Prerequisites

- Different states of matter
- Skills in interpreting symbol diagrams

Model 1:

We know that matter is made up of tiny particles which are often represented by small circles, squares or triangles. Each circles, square or triangle represents an **atom** of matter.

The diagrams below represent some matter. Use them to answer the following questions.



1) How does diagram A differ from diagram B?

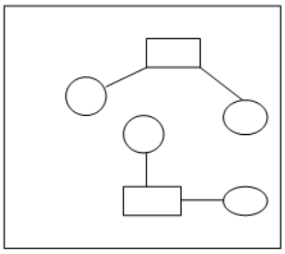
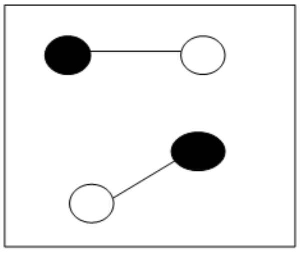
____

____

2) In what way A and B are similar?

____

____

C D

3) How does diagram C differ from diagram D?

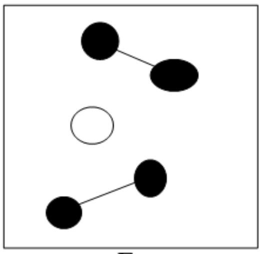
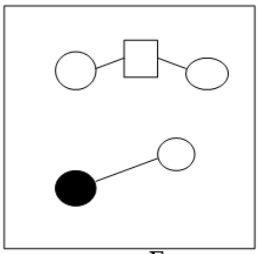
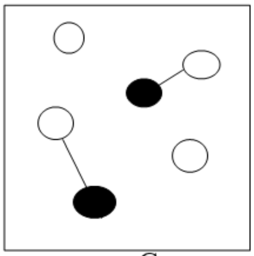
____

____

4) In what way C and D are similar?

____

____

E F G

5) How does diagram E differ from diagram F?

____

____

6) In what way E and F are similar?

____

____

7) How does diagram F differ from diagram G?

____

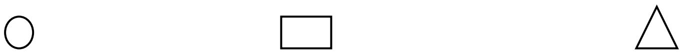
____

8) In what way F and G are similar?

____

____

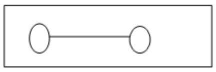
***Atoms* are the simplest form of matter. An atom consists of a single particle of matter.**



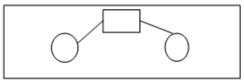
If a particle of matter contains more than one atom then we draw the particle with more squares or triangles than circle, square or triangle or some combination of these.

Particles which contain more than one atom are called <u>molecules.</u>

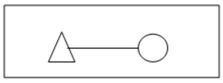
Different atoms in a molecule are joined together by a **bond** which is represented by a single line.



A molecule made up of two identical atoms



A molecule made up of three atoms (two identical and one different)



A molecule made up of two different atoms

9) What is the difference between an atom and a molecule?

____

____

10) Which container holds only atoms?_________________________________

11) Which container holds only molecules?______________________________

12) Diagrams A, B, C and D represent pure substances, diagram E, F and G represent mixtures of pure substances. Use this information to write definitions for a-

Pure substance____

____

Mixture____

____

Exercise questions

1. Use your definition to classify each of the following substances as either pure substance or mixture by putting a tick in the appropriate column.

2. For each of the substance you classify as a mixture, state at least two of the pure substances in it and write them in the last column.

	SUBSTANCE	**PURE SUBSTANCE**	**MIXTURE**	
1	Sea water			
2	A cup of tea			

3	Salt in the salt shaker			
4	Sugar in the bowl			
5	The air you breathe			
6	Hydrogen gas			
7	milk			
8	Silver metal			
9	Beach sand			
10	lemonade			
11	gold			
12				
13				
14				
15				
16				
17				

3. In the table above, write three more examples of pure substances and three more examples of mixtures.

4. For each of the substance you classify as a mixture, state at least two of the pure substances in it and write them in the last column.

Appendix E
Year 8 POGIL worksheets
CLASSIFY (Activity 6)

Why?

The chemical elements are referred to as the simplest form of matter. These elements range from oxygen, we breathe, through to uranium which is used as nuclear fuel. Atoms are the building blocks of elements and different atoms can join together to form chemical compounds ranging from simple table salt to complex proteins.

Success Criteria

- Understand more about atoms and molecules
- Understand the difference between elements and compounds
- Comprehend diagrams
- Drawing up table
- Classifying things

Prerequisites

Skills in interpreting symbol diagrams

Model 1: Beginning

○ Hydrogen	△ Carbon	□ Oxygen	☆ Helium
● Calcium	▲ Nitrogen	■ Chlorine	★ Sulfur

Use the above key to answer the following questions.

1) What shape represents-

Hydrogen_____________ Oxygen____________

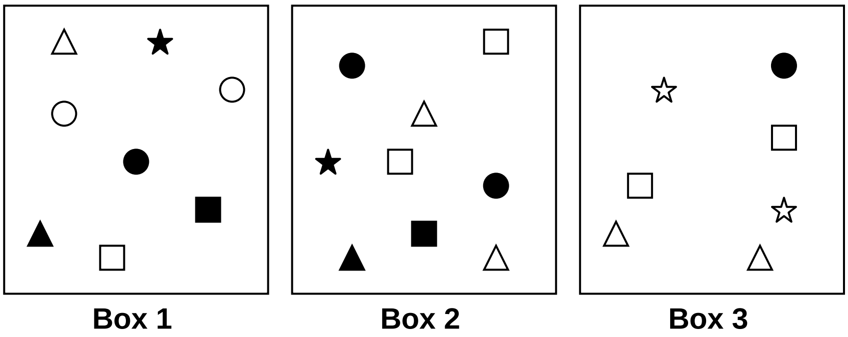
Calcium______________ Sodium____________

Helium_______________ Chlorine___________

The shapes in Model 1 represent on atom of each of the element.

<u>Atoms</u> are the simplest form of matter. An atom consists of a single particle of matter.

Study the following boxes.



1) In box 1 how many different types of atoms are there of each type?

____

2) In box 2 how many atoms of Helium are present?

____

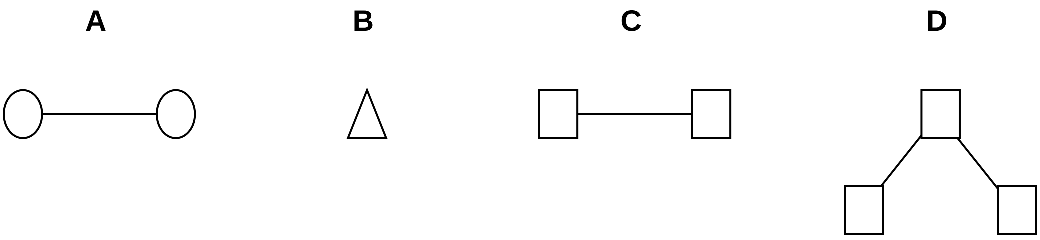
3) Name all the different type and number of atoms present in box 3.

____

4) Name an atom which is present in box 3 only?

____

Model 2: Combinations



Answer the next three questions using Model 2.

1) Which type of atoms exists by it self (single)?

____

2) Which type of atoms exists in combinations?

____

3) From your answer to the above question what is connecting two atoms together?

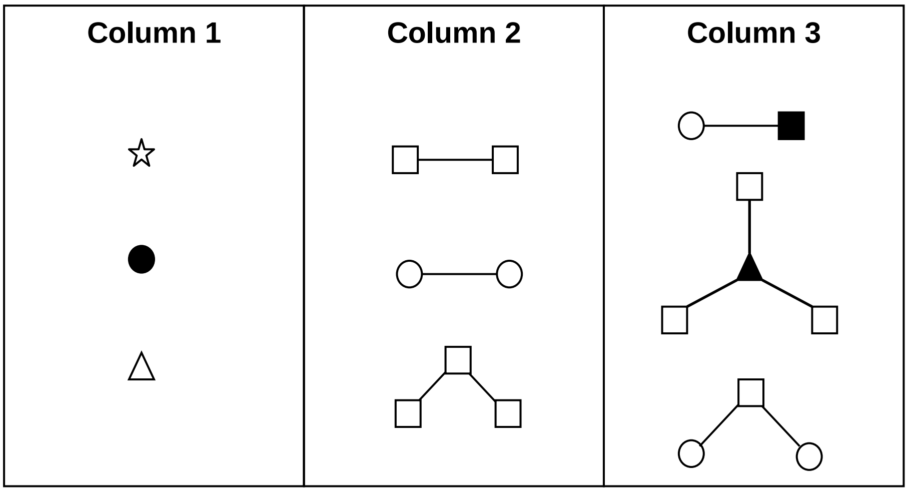
____

***A line** represents a chemical bond joining the atoms together.*

Complete the following table using model 2.

SHAPES	**A**	**B**	**C**	**D**
Number of atoms				
Types of atoms (write their names)				
Number of chemical bonds				

Model 3: more combinations



1) In which column single atoms are present?_______________________________

Mono atomic elements exist in column 1 only.

2) In which column more than one atom is present._________________________

Polyatomic elements exist in column 1 and 2.

3) Using the key in model 1 give two examples from column 1 and write their names.

____

4) Using the key in model 1 write some pairs of atoms from column 2.

____

5) Using the key in model 1 write some atomic combination from column 3.

____

6) What do you understand by the term mono atomic and poly atomic elements?

Mono atomic ____

Poly atomic ____

***<u>Molecules</u>* are made up of two or more atoms joined together by chemical bonds. They are of two types**

a) <u>molecule of an element</u>- has same types of atoms joined together.

7) Which column in model 2 has molecule in elemental form? Draw one molecule of an element from that column.

____

b) <u>molecule of compound</u> –has different types of atoms joined together.

8) Which column in model 2 has molecule of compound. Draw one molecule of a compound from that column.

____

9) In what way column 2 and 3 are similar?

____

____

10) In what way column 2 and 3 are different?

____

____

Molecules ***are made up of two or more atoms joined together by chemical bonds. In molecules the atoms chemically joined together may all be the same (molecule of an element) or different (molecule of compound).***

Elements ***are substances made up of only one type of atom. Some elements exist as atoms (mono-atomic elements) and some exist as molecules.***

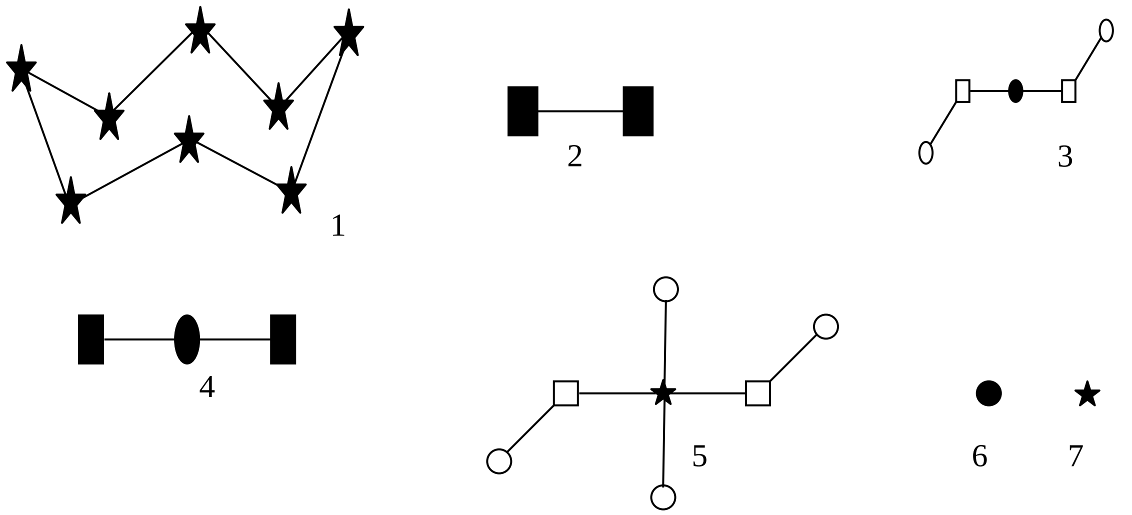
Mono-atomic- One atom

Poly-atomic- more than one atom

Compounds ***are substances made up two or more different elements joined together by chemical bonds. They must therefore be made up of molecules.***

Activity

1) The following diagrams represent either atoms or molecules of elements or compounds. Put them in correct column.



ATOM OF ELEMENT	MOLECULE OF ELEMENT	ATOM OF COMPOUND	MOLECULE OF COMPOUND

There is one column, which is totally empty. There are no diagrams that fit into that classification. Explain this.

2) Draw up another table with similar headings like the one above. Using your own symbols, draw two more examples of each.

3) Using the same symbols in previous models draw each of the following.

a) A molecule of an element which has three atoms.

b) A molecule of a compound which has three types of atoms and a total of eight atoms.

c) A molecule of a compound which has four atoms but only two different types of atoms.

4) Elements can be represented by symbols. Using a periodic table write the symbols of the following elements.

Hydrogen___________	Oxygen____________	Calcium___________
Sodium____________	Helium____________	Chlorine___________

5) Using a periodic table and the information provided in the worksheet draw the following.

a) A molecule of an element which has two oxygen atoms joined together.

b) A molecule of a compound which has two hydrogen atoms and one oxygen atom.

c) A molecule of a compound which has two atoms of hydrogen, one sulfur atom and four oxygen atoms.

d) A compound having one sodium atom and one chlorine atom joined together.

Appendix F

Year 11 POGIL worksheets

Appendix F
Year 11 Chemistry POGIL worksheets
Reactions of acids and bases

Why?

Acids and bases have significant roles in our daily life. These roles range from digestion of food in our stomach to destruction caused by acid rain and formation of limestone caves. Acids and bases react with different substances to form predictable products.

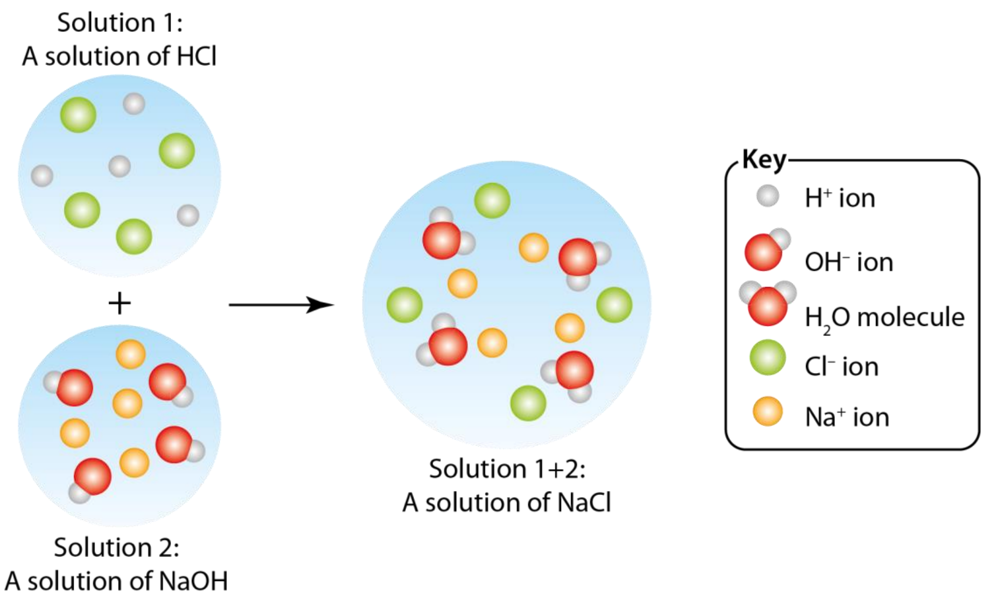
Learning Intentions

- Predict the products for acid base reactions.
- Write net ionic equations.

Success criteria

- To be able to predict the products for acid base reactions.
- To be able to correctly write ionic equations.

Model 1



Questions

1. Name the species present in aqueous solution of HCl in model 1 part (a).

---

2. Name the species present in aqueous solution of NaOH in model 1 part (b).

---

3. Name the species formed when HCl reacts with NaOH:

---

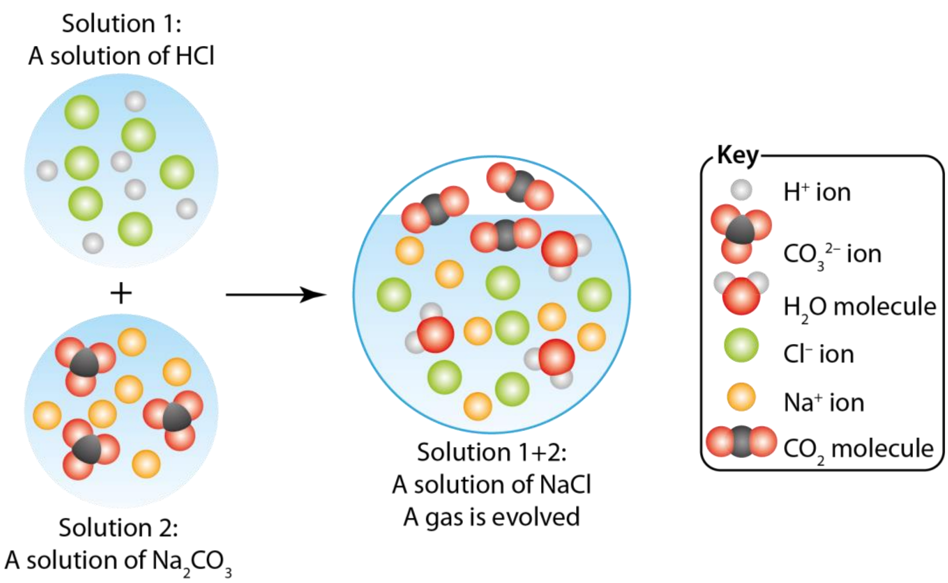
4. Name the species which do not take part in the reaction:

---

5. Write net ionic equation for the above reaction.

The species which do not take part in the reaction are called spectator ions. The spectator ions are not written in the ionic equation.

Model 2



1. Name the species present in aqueous solution of HCl in model 2 part (a).

---

2. Name the species present in aqueous solution of Na_2CO_3 in model 2 part (b).

---

3. Name the species formed when HCl reacts with Na_2CO_3.

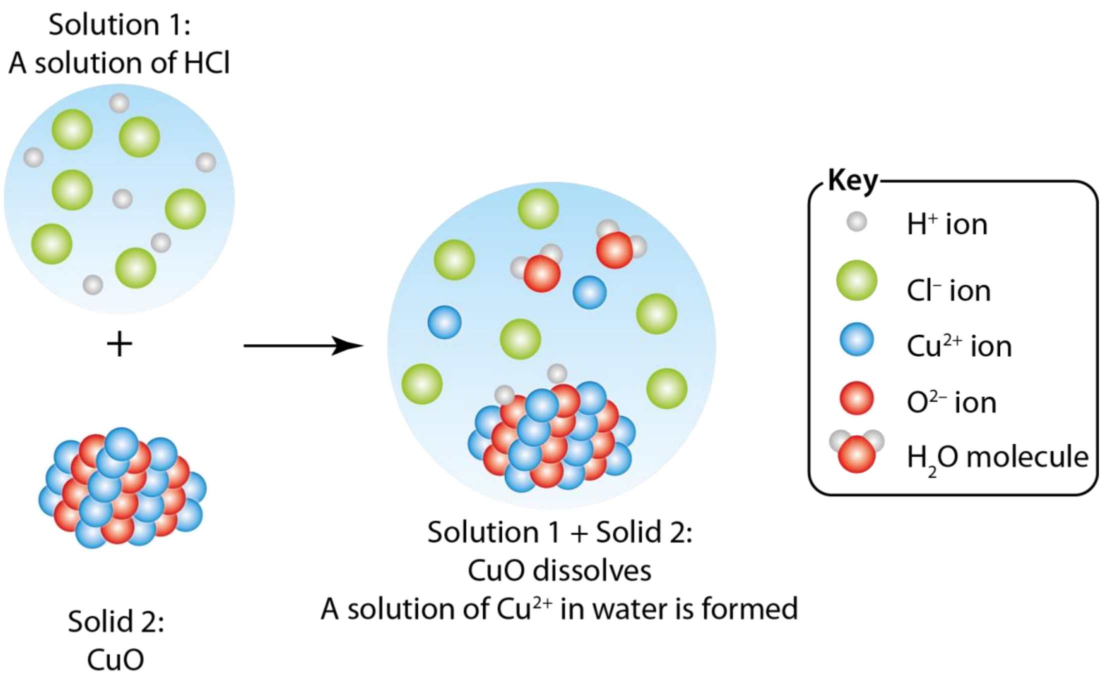
---

4. Name the species which do not take part in the reaction:

---

5. Write net ionic equation for the above reaction.

Model 3



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1. What state of matter is CuO present in model 3 part (a).

---

2. Name the species present in aqueous solution of HCl in model 3 part (b).

---

3. Name the species formed when CuO reacts with HCl.

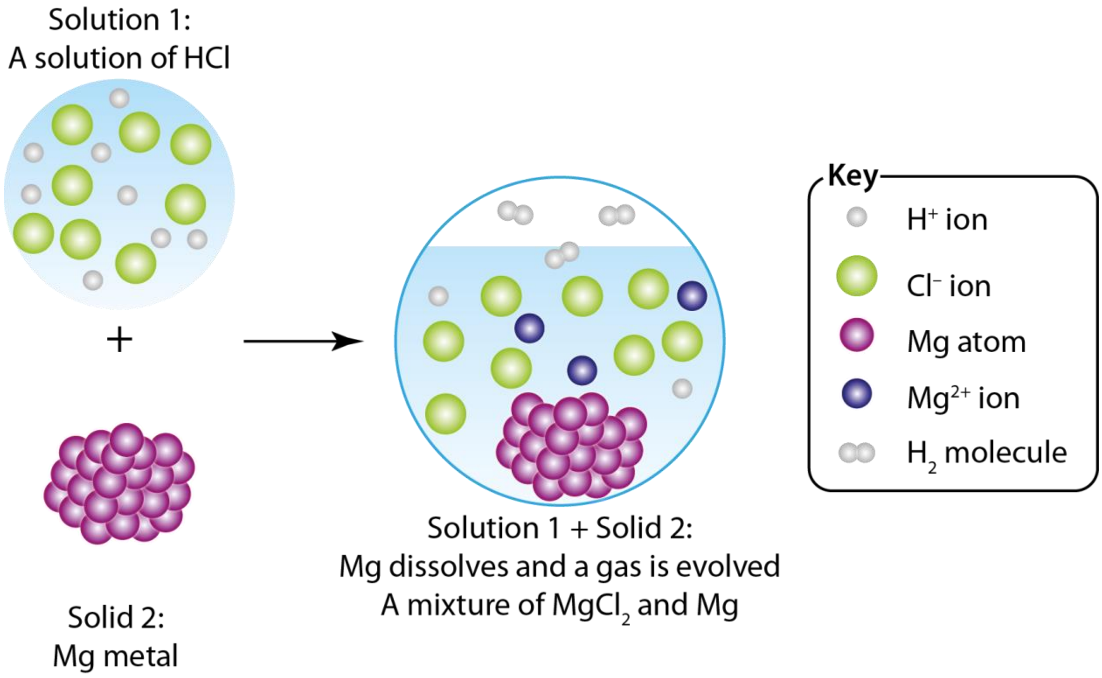
---

4. Name the species which do not take part in the reaction:

---

5. Write net ionic equation for the above reaction.

Model 4



1. What state of matter is Mg present in model 4 part (a).

---

2. Name the species present in aqueous solution of HCl in model 4 part (b).

---

3. Name the species formed when Mg reacts with HCl.

---

4. Name the species which do not take part in the reaction:

---

5. Write net ionic equation for the above reaction.

Complete the following table using models 1,2 ,3 and 4.

GENERAL REACTION	EXAMPLE USED IN THE MODEL	IONIC RECTIONS AND OBSERVATIONS
ACID + BASE ---> SALT + WATER	$H^{+}_{(aq)} + OH^{-}_{(aq)} \dashrightarrow H_2O_{(l)}$ OR $H_3O^{+}_{(aq)} + OH^{-}_{(aq)} \dashrightarrow 2H_2O_{(l)}$ **OBSERVATIONS** Two colourless solutions are mixed and a colourless solution remains.	1. Dil. Nitric acid is added to a solution of calcium hydroxide. **OBSERVATIONS**
		2. Vinegar is added to solid lithium hydroxide **OBSERVATIONS**

GENERAL REACTION	EXAMPLE USED IN THE MODEL	IONIC RECTIONS AND OBSERVATIONS
		1. Dil. acetic acid (vinegar) is added to solid nickel oxide $2CH_3COOH_{(aq)} + NiO_{(s)} \dashrightarrow H_2O_{(l)} + Ni^{2+}_{(aq)} + CH_3COO^-_{(aq)}$ **OBSERVATIONS-** Green solid dissolves to form a green solution and the vinegar smell disappears.
		2. Solution of sulfuric acid is added to solid magnesium oxide **OBSERVATIONS**

GENERAL REACTION	EXAMPLE USED IN THE MODEL	IONIC RECTIONS AND OBSERVATIONS
ACID + METAL HYDROGEN CARBONATE → CARBON DIOXIDE + WATER + SALT SOLUTON		1. 0.1 mol/L sulphuric acid solution is added to solid copper carbonate **OBSERVATIONS-**
		2. a solution of potassium hydrogen carbonate is added to dilute nitric acid. **OBSERVATIONS**