REFINING PROCESS-ORIENTED GUIDED INQUIRY LEARNING FOR CHEMISTRY STUDENTS IN AN ACADEMIC DEVELOPMENT PROGRAMME

Christine Mundy* and Marietjie Potgieter

University of Pretoria, Pretoria, South Africa

*Correspondence to Christine Mundy christine.mundy@up.ca.za

Abstract

In this study, action research was used over two years to refine the implementation of process oriented guided inquiry learning for chemistry students in an academic development programme at a research-intensive South African university. Students' responses to guided inquiry were collected based on a three pillar framework underpinned by Cognitive Load Theory and the Information Processing Model. A mixed methods approach was used to gather data including observations, questionnaire responses, focus group interviews and student assessment results. The findings are exhibited year by year using the analysis tool, 'joint displays'. Findings from the first year of study highlighted student difficulty with factors contributing to extraneous load such as social dynamics, worksheet layout and time required. Revisions addressed these areas of difficulty in the second year with positive results in terms of student behaviour and achievement. Analysis of Year 2 findings lead to several recommendations for further guided inquiry revisions to serve novice students in the context of an academic development programme: prior knowledge should be activated to mitigate cognitive overload, relevant language should replace foreign terms to sensitise the perception filter, and, more explicit scaffolding could be embedded to enrich the student's germane cognitive load during processing.

Keywords

South Africa; chemistry; academic development programme; POGIL; cognitive load

Introduction

Academic development programmes, in the form of extended, foundational or augmented programmes, have been prevalent in South Africa for the past 30 years (Shay, Wolff, & Clarence-Fincham, 2016). South African academic development programmes are similar to preparatory or remedial tracks in that they bridge the gap between high school and tertiary education, but are dissimilar in that most South African academic development programmes are not separate courses, but are built-in to the curriculum of a baccalaureus degree as an extension of the first year (Engelbrecht, Harding, & Potgieter, 2014).

In the case of this study, students who do not meet the requirements for a three-year baccalaureus degree have the opportunity to enrol in a four-year extended degree. It is assumed that students entering this academic development programme are not adequately prepared for the STEM subjects which they will encounter, where preparedness is defined as conceptual knowledge and understanding, supported by prerequisite mathematical skills and academic literacy (Potgieter & Davidowitz, 2010). Key aspects of successful academic development programmes are the holistic support offered (Grayson, 1996), additional time spent building strong foundational knowledge and skills at first year level (Shay et al., 2016) and a concerted institutional drive to meet the needs of the students (Ogude, Kilfoil, & Du Plessis, 2012).

POGIL

In this study, we aimed to contribute to student success in the first year general chemistry module by exploring Process-Oriented Guided Inquiry Based Learning (POGIL) as a potential instructional approach in the academic development programme. POGIL sits within a wave of interpretations of collaborative and cooperative instructional approaches - this wave is critically expanded on by Johnson and Johnson (2009) in their review paper. Specifically, POGIL is a teaching and learning approach which began in 1994 in college chemistry in the USA, however, it has been adapted in other regions (Kaundjwa, 2015; Treagust et al., 2018).

POGIL has been shown to increase student confidence (De Gale & Boisselle, 2015), problem solving abilities and performance (Farrell, Moog, & Spencer, 1999; Hein, 2012). These attributes are desirable for any cohort of students, however, several local academic development programmes have found the constructivist pedagogy (Kirby & Dempster, 2011) and student engagement in small group activities (Pym, 2013) particularly promising.

In this study the topics of the *mole concept and stoichiometry* and *redox reactions* were chosen for the POGIL intervention as both topics are known for their challenges both nationally and internationally (Johnstone, 2010; Potgieter & Davidowitz, 2010).

Instructional design of POGIL

In a POGIL classroom students are divided into groups of 3 to 5 students, each with their own role and responsibility within the group; in this manner they work together on specially designed guided inquiry worksheets, guiding each other (Moog, 2014; Moog & Farrell, 2008). The frequency of allocating students into new groups is variable; however, their roles within a group should change on a daily basis. There are five roles within the group: manager, recorder, technician, reflector and presenter – the role changes are done for the benefit of the students, enabling them to develop confidence in a variety of professional and life skills (Farrell et al., 1999).

The guided inquiry worksheets consist of three basic parts (Farrell et al., 1999, p. 571): initially students are presented with data i.e. a "figure, an equation, a table, text, or any combination of these". Exploration of the data should provide the starting point for the development of chemical concepts. In the second part of the worksheet, critical thinking questions are used to aid student concept invention and conclusions by highlighting patterns and relationships in the data. The final part of the worksheet is application, which is often prescribed as homework so that students can individually apply what they discovered as a group.

Pedagogical underpinning of POGIL

The Learning Cycle is a data driven theory which negotiates the inquiry-based nature of the scientific method and thus learning (Abraham, 2005). Strong parallels exist between the three core phases of the Learning Cycle - exploration, concept invention and application - and the structure of the guided inquiry worksheets (Moog, 2014). Inquiry based learning facilitates the “independent discovery of knowledge” and it is maintained that if students construct knowledge and concepts for themselves, it will hold a greater meaning for them and hence be retained in a more permanent manner in the mind of the learner (Abraham, 2005).

The Learning Cycle and POGIL are nestled in the paradigm of social constructivism in which it is maintained that knowledge evolves through social negotiation. Piaget (1964) refers to this negotiation as the re-establishment of an equilibrium, interrelated with the active process known as self-regulation. This re-establishment is based on an initial dissatisfaction with existing conceptions. Facilitating this social negotiation is the allocation of students to assigned heterogeneous POGIL groups. Additional benefits of heterogeneous groupings include students learning from each other and solving problems which they may not have been able to do individually (Gulacar, Eilks, & Bowman, 2014).

Conceptual Framework

Students in an academic development programme bring with them various personal factors such as prior associations and learnt social dynamics. There are also variations in students' prior knowledge and English language proficiency. In an attempt to collate all of these variables under the influence of a new pedagogical approach, the conceptual framework for this study was built around the Information Processing Model (IPM) and Cognitive Load Theory (CLT).

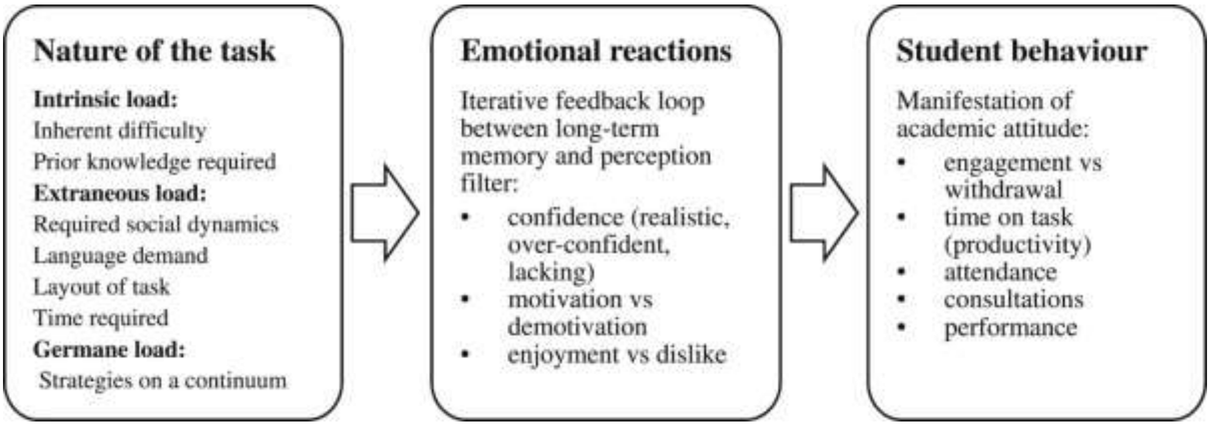


Figure 1. Conceptual Framework: Three pillar framework for evaluating students' responses to novel pedagogical approaches

IPM describes individual student learning: how external stimuli pass through a perception filter, are processed in the working memory and then enter the long-term memory for storage and recall (Johnstone, 1997). The working memory is a space in the mind where information is held and processed before the possibility of storage in the long-term memory. CLT seeks to understand the factors which influence the availability of working memory, and CLT can be applied when determining the effectiveness of learning materials (Chandler & Sweller, 1991). According to Paas, Renkl and Sweller (2003), cognitive load comprises of intrinsic, extrinsic and germane load.

The first pillar in the conceptual framework (Figure 1) describes the nature of the task, or pedagogical approach chosen, in this instance it was POGIL. The first pillar is informed by the three components of CLT. Intrinsic cognitive load centres on students' capacity to understand new information given their prior knowledge and the inherent difficulty of the topic at hand. The extraneous cognitive load complicates the processing of information in the mind of the students, it places peripheral demands on the learner characterised in the three pillar model as social, language, layout and time demands.

Germane load is perhaps the most difficult to understand, in broad terms it is the processing required for schema construction, assimilation and accommodation in the long term memory. Germane load is embedded in the learning materials in the form or scaffolding, cues, worked examples, or it can be precipitated in the mind by guiding questions or incomplete solutions (Sweller, Van Merrienboer, & Paas, 1998). Mechanisms of scaffolding lie on a spectrum and can be employed based on the requirements of the situation and the needs of the students, the "fading" of scaffolding is a technique in which less germane support is given as the working memory capacity of the students increases (Paas et al., 2003).

The second pillar of the conceptual framework deals with the effect that the long term memory has on the perception filter, it serves to either sensitise or de-sensitise students to incoming information. "The learner attends to what is familiar, stimulating, interesting, surprising or exciting" given the frames of reference stored in long term memory (Johnstone, 2006, p. 55). Students have emotional reactions to different pedagogies and to different content based on past experiences, for example "group work" conjures a spectrum of emotions depending on the student, likewise, "Euclidean geometry" might be recalled with dislike or feelings of happiness and confidence.

The nature of the task (pillar 1) elicits students' emotional reactions (pillar 2) which may not always be explicit. However, the combination of these two pillars manifests in the third as student attitudes and academic behaviours. Student behaviour has both subjective and objective measures (Conard, 2006). In terms of this study, productivity and participation, time management and engagement constitute the subjective measure whereas attendance and performance can be measured directly. Student behaviour is of interest to both the practitioner and the researcher, as it is a good predictor of student success, and thus the success of the pedagogical approach used. It is necessary to mention that the three pillar framework was designed as a comprehensive view of student responses. Only some of the components will be discussed in this paper.

Research Questions

The following questions guided the research study:

1. How do students respond to the nature of POGIL?
    a. What are the students' experiences of POGIL?
    b. What types of student behaviours were observed during the POGIL intervention?
2. What are students' preferences towards POGIL as compared to traditional instruction?
3. How does POGIL influence student performance?

Methodology

Action research methodology was chosen as it is a practical tool used by educators (Denscombe, 2014). The researcher was the instructor in this study, giving a strong participatory element to the action research. Action research lends itself to variety of data collection methods that were required in this study given the scope of the conceptual framework and research questions.

The study ran over two years, with a fresh intake of students per year. The initial research into POGIL informed the implementation in Year 1, the reflections at the close of the first year fed into practice in the second year. The implementation took place in the last quarter of each academic year, to coincide with the teaching of the chosen topics of the *mole concept and stoichiometry*, and *redox reactions*. This allowed a generous amount of time for reflections and revisions before re-implementation in Year 2.

Sample description

The student participants were equally distributed in terms of gender and diverse in terms of race and socio-economic status. The vast majority of the participants were English second language speakers (82.2% in Year 1 and 75.8% in Year 2). Some students only encountered English as a mode of instruction in the academic development programme.

In the first year of the study, 249 students were enrolled in chemistry and 241 students enrolled the following year. Students attended one two-hour lecture and one two-hour tutorial session per week. Students attended tutorials in fixed smaller groups - this grouping had no set criteria. The grouping was done so that students may receive more personalised attention during tutorials. One tutorial group per year was chosen randomly to experience the POGIL approach: Year 1 ($n = 50$ students) and Year 2 ($n = 35$). The remainder of the students enrolled acted as a reference group: Year 1 ($n = 199$ students) and Year 2 ($n = 206$). Prior to the commencement of the study, The POGIL and reference group were shown to have no statistically significant difference in performance prior to the intervention based on the students' first semester mark, the nonparametric Kruskal-Wallis test was used at 5% significance ($p = 0.716$). This procedure was repeated in Year 2, and again no statistically significant difference was found ($p = 0.133$).

Implementation

The reference students attended their tutorials after having the content delivered in the lectures. During the tutorials, students worked through prescribed problems and exercises with a tutor present to provide assistance when required. This is a flexible environment in which students often volunteer to share their answers with the class. Occasionally, the tutor will tackle a problem on the board that many students appear to be struggling with.

The POGIL group attended tutorials before attending lectures, to adhere to the pedagogy of students exploring and constructing concepts for themselves, thus the lectures served as consolidation in the *mole concept and stoichiometry*, and *redox reactions*. Each topic was allocated three weeks in the curriculum. That is, the students experienced POGIL for a quarter of the academic year.

To ensure fidelity of implementation, the instructor attended a POGIL seminar, presented by a POGIL specialist, prior to the commencement of the study. The instructor relied on 'Chemistry, A Guided Inquiry' (Moog & Farrell, 2008) for the POGIL worksheets used in the tutorial sessions. The worksheets were not altered in any way in Year 1. In preparation for implementation in Year 1, the instructor formed small groups of 5 students each. The small groups were heterogeneous, having strong, poor and moderate performers based on students' chemistry performance in the previous semester. Small groups were fixed but roles changed in every tutorial session.

At the commencement of the POGIL approach, the motivation for the study, guidelines of the approach and literature documenting cases of student success were presented to the student participants. Students were keen to engage in POGIL each year. Ethical clearance was granted before the commencement of the study and students provided informed consent.

Data collection methods

Data were collected in five ways. Firstly, daily observations were noted in a journal by the instructor of the experimental group, who was also the researcher. The instructor was well experienced in tutoring chemistry before the commencement of the study. The journal observations focussed largely on the first pillar of the conceptual framework (the nature of the task) and the last pillar (student behaviour). Journal entries had two parts: general observations followed by reflections.

The POGIL tutorial group were observed by two other chemistry tutors, John and Jane (pseudonyms). John and Jane were experienced tutors who dealt with the other tutorial groups which made up the reference group. Observations were conducted at the start and late stages of each intervention. The observations were guided by a set checklist provided by the researcher based on the last two pillars of the conceptual framework: Emotional reactions and Student behaviour. John and Jane also took the liberty of engaging the student participants in informal interviews during the observation settings to further probe the emotional perspectives of the participants in real-time.

Focus group interviews were conducted after the completion of the POGIL approach. Two academically representative groups of 3 to 5 students were selected per year. Student anonymity was a priority. The interviews were semi-structured, recorded and transcribed by the researcher. The interview instrument was designed to promote reflection on the POGIL experience and illicit motivations for student preferences when comparing the traditional approach to the POGIL approach. The transcripts were coded deductively, with the first two pillars of conceptual framework providing the lens for analysis.

A short multiple choice questionnaire was administered to each student in the POGIL tutorial group, to gauge general attitudes towards the POGIL approach. This was done at the end of the semester, before the exam period. The questionnaire was designed by the researcher, and its content was based on data collected from the observations and focus group interviews. Student responses were anonymous.

Student assessment results in written examination questions where responses to the questions on the two topics were self-constructed, that is, students clearly presented their methodology and subsequent answers in writing, and were then scored by an examiner.

Analysis

To fully appreciate the findings from the variety of data sources, joint displays were used. A joint display is a means of integrating or merging vast quantitative and quantitative databases (Creswell & Plano Clark, 2017). It is stressed by Fetters and Freshwater (2015) that a joint display is not just an analysis tool, but an elegant presentation of data for publication and dissemination. The construction of a joint display provides the structure necessary for integrated analysis discourse and high quality insights and inferences (Guetterman, Fetters, & Creswell, 2015).

For this study, one joint display was constructed per year. The components of all three pillars were used deductively to select the qualitative findings displayed. The findings from each data source were triangulated against each other **before** inclusion, to ensure the highest quality in the joint-displays. In the top left, quotations from the observers (John and Jane) are presented. These external observations were coded as O1, O2 etc. in the original transcripts. Alongside the external observations are the instructor's journal observations, coded J1, J2 etc. in the upper right quadrant. The instructor's observations were the result of chronological journal observations which were distilled into small paragraphs. Below the two upper quadrants is a section displaying quotations from the student focus groups. The coding system FG1, FG2 etc. was used. These three qualitative data sources were selected to explore the two components of the first research question: How do students respond to the nature of POGIL in terms of their experience and in terms of their behaviour?

The lower left quadrant contains response data to the questionnaire item "I would recommend that this approach used next year instead of the original way in which our tutorials were structured". This response data was used to answer research question 2, which probed student preference for POGIL. The response rates were 78% and 56% respectively in Year 1 and 2. The findings used to answer the final research question are presented in lower right quadrant: the performance of the POGIL group in comparison to the larger reference group. As group sizes differed, non-parametric tests were conducted. Dunn's post-hoc pair-wise test was performed at a 5% significance level.

Findings and Reflections: Year 1

The presentation of the findings for Year 1 refers to the joint display in Figure 2.

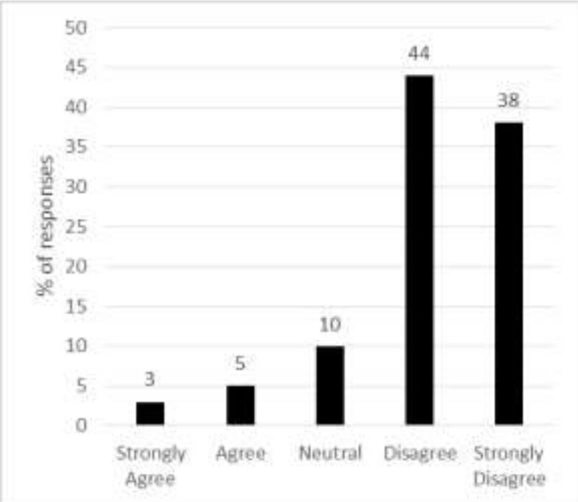
Figure 2: Joint display for Findings of Year 1

External Observations	**Instructor's Observations**
John, early on in the implementation "Perhaps the fastest ones in a group got bored, but they could alleviate that by teaching some of their slower peers" O1 "Are they learning? I'd say they are getting a different way of learning, I think it is a good way to get concepts across" O9 **Jane, later in the implementation** "the students battled to use the allocated time well, most failed to complete the worksheet" O21 "students felt as if they were not getting enough feedback regarding the work" O11 "the stronger and faster members have a tendency to leave the weaker and slower members behind" O2 "I found that the students did not enjoy working in groups" O31	Students were motivated and productive initially (J1). Perhaps this is because students are out of their "comfort-zones"? The worksheets need spaces for students to answer the critical thinking questions – disjoint questions and answers are problematic (J2). From the second tutorial session onwards late-comers and absenteeism increased (J3). Groups were re-shuffled as the members were assumed absent (some groups only had one member at the start of the tutorial) and this caused problems when late students arrived and had to find groups (J4). POGIL requires a large amount of time for students to settle into their roles and start on the tasks (J5). Extra time is also needed to "coach" the students in the desired answer format for assessment (J6).
Focus Group Interviews "We were not able to cover a lot of work, I think we were able to cover the most important stuff and then after that you can also go home and find out for ourselves" FG26	

"When I get stuck I just lose concentration and I don't do work anymore. That kinda made me fall behind. So when it came to tests and stuff, I had to start from the beginning and do self-study" FG16
"I hate teamwork and I don't think it's productive. So I wouldn't recommend POGIL" FG38
"I'm happy with the layout but I did think that we did start with the most easiest questions so that we can get started, and then after that, we got to the more difficult questions" FG 50
"If I hadn't done the tutorial, I don't think I would have got any marks (in the test)" FG17
"If I was given, um a role for presenting I would be scared like the whole session that I have to speak in public and stuff. I couldn't really concentrate" FG7

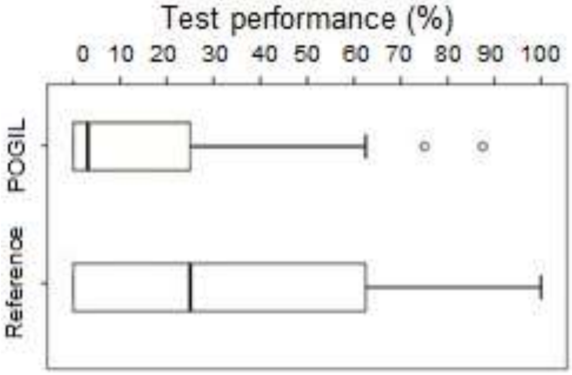
Questionnaire results

"I would recommend that this approach used next year instead of the original way in which our tutorials were structured."



Box and whisker plot of student test performance

		M ± 1 SD	Mdn
POGIL	n=50	14.5 ± 22.1	13.2%
Reference	n=299	33.6 ± 33.6	25.0%



A significant difference lay in student performance between POGIL and the control ($p<0.0001$, $d=0.67$)

In terms of the Nature of the Task, the novel learning style appeared to work well at the beginning if the intervention (O9). Students drew attention to the fact that the scaffolding of the critical thinking questions progressed from easy to more challenging, and appreciated this in the layout. However, due to time constraints, much of the challenging work was left as self-study (FG26 + FG50). Time was overarching as a limiting factor: a significant amount of time was required before engaging with the critical thinking questions (J5), which was exacerbated by late-coming as the semester progressed (J3 + J4). Students battled with time management in general (O21 + FG26) with observed negative effects for weaker students (O2).

Additionally, feedback was challenging – the students were unconfident in their answers and answer format (O11) and the facilitator often lacked the time to address this (J6). This challenge is rather specific to the context of the study – students in the academic development programme often lack confidence in their own work and look to the instructor for guidance, this is at odds with the student-centred nature of POGIL. Furthermore, the philosophy of POGIL encourages the building of concepts and self-constructed emergent solutions which is contrary to the general format of instruction on the academic development programme where students are taught to solve problems with accepted scientific conventions to prepare them for later studies.

Initially, the POGIL approach appeared promising, in terms of Emotional Reactions and Student Behaviour, with students exhibiting satisfactory motivation and productivity (J1).

However, only a small percentage of student questionnaire responses showed preference towards POGIL at the end of the implementation. The academic attitude of the students swiftly deteriorated due to students' Emotional Reactions to the social dynamics prerequisite to the Nature of the Task (O31, J3 + FG38). Understandably, the alteration of academic attitude, and the fact that students were not able to accomplish the prescribed work in the allocated time, resulted in poor performance for the POGIL group in the joint assessment of the *mole concept and stoichiometry*, and *redox reactions*.

Revisions

The revisions for the second year of implementation were numerous but small – the integrity of the POGIL approach was still maintained. The revisions centred on the first pillar of the conceptual framework as Emotional Reactions and Student Behaviour flow from this starting point. To ease social discomforts, it was decided that students should be allowed to choose their own groups at the start of each POGIL tutorial. This flexibility was expected to solve the problem raised by absenteeism in the first round of implementation. Another revision strategy was to decrease group sizes from 5 to 3 members as this should increase individual responsibility and involvement. To accomplish this, the roles were condensed so that each group had a manager, a recorder and a "general secretary" who kept time and was responsible for all technical work like operating the calculator. The role of presenter was omitted in the second year, as not enough time was available in a tutorial session for presentations and this role appeared to stress many of the students, especially those for whom English was a second language (FG7). To aid the groups in time management, time allocations were added next to each question in the guided inquiry worksheets. Space was also provided for students to complete their answers on the guided inquiry worksheets, instead of on separate sheets of paper.

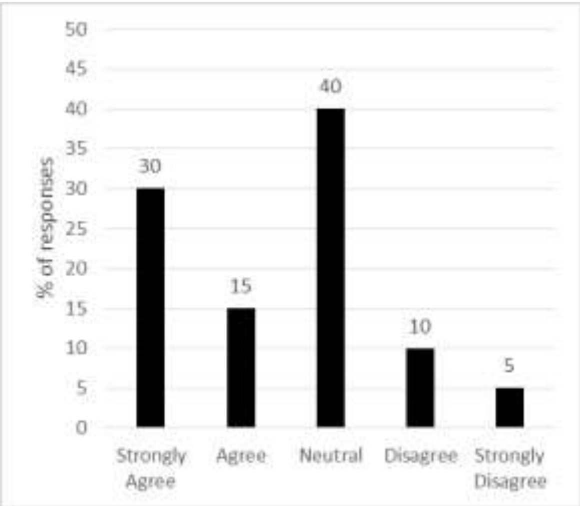
Findings and Reflections: Year 2

The presentation of the findings for Year 2 refers to the joint display in Figure 3.

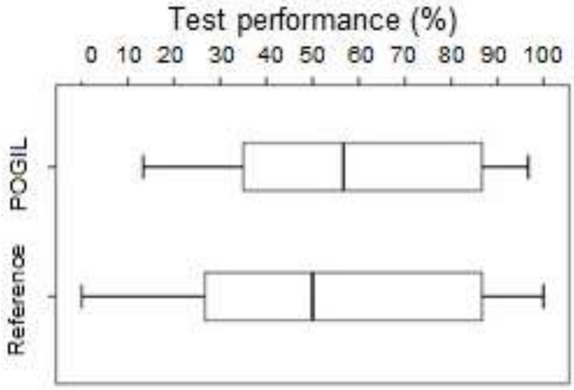
Figure 3: Joint display for Findings: Year 2

External Observations	**Instructor's Observations**
(Unfortunately the intervention could not be observed in the early stages of implementation) **Jane, later in the implementation** "I found that group dynamics wasn't as big a problem this year" O3 "This year group members were allowed to choose the role that they would play in the group. These roles suited the shy and more insecure students a bit better as it did not put unnecessary pressure on them to present" O4 "I found that the students enjoyed working in groups and that they liked POGIL" O34 "I was very concerned about how naive the students appeared about the complexity of the work and how they all seemed to be overestimating themselves" O12 "stages where the entire group was distracted and involved in a conversation about other	Diligence, punctuality and attendance were maintained by the students for the duration of the implementation (J7). Students worked well in groups of their own choosing (J8). Students used the time allocations appropriately and completed the work in the 2 hour session (J9). Having fewer students in the POGIL group this year (35 vs. 50) allowed for better use of space and the facilitator acting in an improved capacity (J10). At the mid-point of third session students were disengaged and withdrew when confronted by challenging questions and strange terms, e.g. "gross" and "s'more" (J11). Students' mood affects the implementation of POGIL, if they have external stressors e.g. an upcoming test, the time taken to begin and then to complete critical thinking questions is prolonged (J12).

<table>
<tr><td>topics (especially the groups of friends)” O22</td><td></td></tr>
<tr><td colspan="2">Focus Group Interviews
“I’m not really a group person, so it was challenging to listen to others” FG1
“I felt like POGIL’s pace was a little too fast” FG2
“It is not always chemistry like you are going to see in the exam, it’s applications to like ‘tree stumps’” FG3
“We are not sure if our answers are correct, if we learn the wrong step, we will apply it wrong” FG4
“I feel like I was wasting time, I could do it on my own and have my own questions (instead of answering others)” FG5</td></tr>
<tr><td>Questionnaire results
“I would recommend that this approach used next year instead of the original way in which our tutorials were structured.”



</td><td>Box and whisker plot of student test performance
M ± 1 SD Mdn
POGIL n=35 58.2 ± 28.1 56.7%
Reference n=206 54.8 ± 29.9 50.0%



No significant difference between the performance of the POGIL group and the reference group (p=1.000, d=0.12)</td></tr>
</table>

The implemented revisions to the Nature of the Task translated into vastly improved findings for Year 2. POGIL students now achieved similar assessment results when compared to the reference group. Student Emotional Reactions observed were that of enjoyment (O34) and students’ preferences towards POGIL were in stark contrast with the questionnaire results of the previous year. Social dynamics were improved (O3, O4 + J8), however, isolated instances of non-academic behaviour were observed (O22). POGIL was still difficult for some students to endorse (FG1, FG5 + questionnaire results) - this can be expected as learning styles do vary.

POGIL could be better moulded to fit the academic development programme if analogies and terminologies used in the tasks were relevant to the curriculum (FG3) or at least familiar to the South African student (J11). When comparing the two topics, i.e. the *mole concept and stoichiometry*, and *redox reactions*, students encountered fewer challenges with the latter. In terms of chemistry content, specific observations by the instructor relate to the critical thinking questions in each topic. Critical thinking questions are designed to encourage concept invention, from simple to multifaceted concepts. It was noted that students found critical thinking questions linking the concepts of concentrations at equilibria ***and*** redox reactions challenging. For example, students are given the following data at STP and asked to write a balanced redox reaction: Metal bar = Co, Ion solution = 1.0 M Ni^{2+}, Concentration of ions at equilibrium Ni^{2+} = 0.1 M and Co^{2+} = 0.9 M. Students battled to understand that the concentration of cobalt ions would be 0 M before the metal bar is added to the nickel (II) solution. The high concentration of Co^{2+} at equilibrium indicates that oxidation of the cobalt bar must have occurred. However, all other questions and exercises asking students to balance reactions and indicate oxidation states and agents were accomplished with relative ease probably due to their procedural nature.

In the mole concept, the groups found the initial critical thinking questions more challenging to discuss than the subsequent questions and exercises. "How many legs are found in one mole of elephants?" and "How many gross of S'mores can you make?" were examples of initial critical thinking questions exploring relationships and proportionality which students battled with. Students appeared more comfortable with what could be considered ***more*** conceptually challenging problems like "How many carbon atoms are found in 0.500 g of glycine, H_2NCH_2COOH?" This may be because students had already experienced these types of problems at high school level and had been provided with formulas to solve the problems. Surprisingly, students experienced challenges explaining fundamental questions dealing with simple concepts such as the proportionality of the number of legs on elephants.

In returning to the joint display (Figure 3) focussing on Pillar 2, students still appeared to lack confidence in their abilities (FG4), which is paralleled by the external observation of naivety (O12). For the most part, students were observed as productive when given time allocations (J9) however some students did voice concerns that the pace was too fast (FG2). Time allocations were only effective in critical thinking questions that were relatively low in inherent difficulty (J11).

In summary, Year 2 revealed different insights compared to the previous year including the challenges of managing non-academic behaviour, productivity break-down in complex situations and student discomfort with foreign terminology. It is unclear whether these challenges were absent in Year 1 or obscured by the extraneous factors mentioned previously.

Discussion

After Year 1, revisions were planned to the nature of the task; these revisions included altering the physical layout of the POGIL worksheet and adding time allocations per question. Additionally, the social dynamics were changed through modifying the size of the groups, enabling the self-selection of group members and revising the students' roles within the groups. In Year 2, it can be seen that the students' emotional responses were observed to have improved along with improvements in student behaviour. The second research question, *What are students' preferences towards POGIL as compared to traditional instruction?* can be evaluated in the shift in student preference from Year 1 to Year 2, as graphed in the questionnaire item. In returning to the final research question in Year 2, the POGIL approach did not yield any performance benefits when compared to the reference group.

When reflecting on the findings of the second year it is plain to see that future revisions must support intrinsic and germane load. The inherent difficulty of the topics of the *mole concept and stoichiometry*, and *redox reactions* cannot be disputed but activating the prior knowledge of under-prepared students in an academic development programme could be addressed through a flipped classroom approach to improve the recall of prior knowledge and thus improve processing during POGIL tutorials.

POGIL supports germane cognitive load through the use of guided inquiry, naturally, this demands higher cognitive skills of the student. In this study, students began to struggle when guided inquiry was combined with challenging content and a lack of confidence. It is proposed that students in this situation were facing cognitive overload which culminated in "performance collapse" (Reid, 2008), therefore, there may be advantages to further embedding explicit scaffolding and cues in POGIL activities in an academic development programme. Additionally, Janssen, Kirschner, Erkens, Kirschner and Paas (2010) highlight the risk of cognitive overload in collaborative learning environments, as present in this study.

As the complexity of the material increased, further demands were also placed on students in terms of language and linking disparate sources of information, not to mention simultaneously juggling group dynamics. Furthermore, for second language English speakers (which make up at least three quarters of the cohort in each year), the cognitive demands of interpreting English in the classroom are up to 25% higher, as students "are faced with an even more complex task of dealing with the processing of two unfamiliar languages, that of science and that which is used as the medium of instruction" (Johnstone & Selepeng, 2001). By using familiar or relevant terminology in future worksheets, these cues may more easily be recollected from the long term memory of the South African student.

Conclusion

Perceptions of teaching and learning are shifting, this study continually sought to meet students "where they are" instead of pitching instruction at a level that may be setting the students up for disillusionment or failure (Stronge, 2018). Of the many promising pedagogical approaches which exist, POGIL was selected for several reasons: the constructivist nature, the student-centred learning style, the promotion of professional skills, the enhancement of student confidence, the adaptability in different contexts and the prospect of improved student performance. However, the findings of Year 1 clearly showed that pedagogical approaches developed and proven elsewhere are often context dependent and should be tried and refined within unique contexts. Action research was vital in moulding POGIL towards meeting the needs of the students, with further iterations of the action research cycle an even better fit may be achieved. For academic development programmes this study shows the benefits of taking into account students' emotional and behavioural responses when reviewing the nature of the task at hand. The three pillar conceptual framework which combined IPM, CLT and student behaviour proved to be a satisfactory tool to guide the study, providing a lens with which to interpret wide ranges of data, and a guide for revisions in the yearly cycle.

References

Abraham, M. R. (2005). Inquiry and the learning cycle approach. In N. J. Pienta, M. M. Cooper, & T. J. Greenbowe (Eds.), *Chemists' guide to effective teaching* (pp. 41-52). Upper Saddle River, NJ: Prentice Hall.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction, 8*(4), 293-332.

Conard, M. A. (2006). Aptitude is not enough: How personality and behavior predict academic performance. *Journal of Research in Personality, 40*(3), 339-346

Creswell, J. W., & Plano Clark, V. L. (2017). *Designing and conducting mixed methods research.* Sage publications.

De Gale, S., & Boisselle, L. N. (2015). The Effect of POGIL on Academic Performance and Academic Confidence. *Science Education International , 26*(1), 56-79.

Denscombe, M. (2014). *The good research guide: for small-scale social research projects.* UK: McGraw-Hill Education.

Engelbrecht, J., Harding, A., & Potgieter, M. (2014). Evaluating the success of a science academic development programme at a research-intensive university. *African Journal of Research in Mathematics, Science and Technology Education, 18*(3), 287-298.

Farrell, J. J., Moog, R. S., & Spencer, J. N. (1999). A guided inquiry general chemistry course. *Journal of Chemical Education, 76*, 570- 573.

Fetters, M. D., & Freshwater, D. (2015). Publishing a methodological mixed methods research article. *Journal of Mixed Methods Research*, 9(3), 203-213.

Grayson, D. J. (1996). A holistic approach to preparing disadvantaged students to succeed in tertiary science studies. Part I. Design of the Science Foundation Programme (SFP). *International Journal of Science Education, 18*(8), 993-1013.

Guetterman, T. C., Fetters, M. D., & Creswell, J. W. (2015). Integrating quantitative and qualitative results in health science mixed methods research through joint displays. *The Annals of Family Medicine, 13*(6), 554-561.

Gulacar, O., Eilks, I., & Bowman, C. R. (2014). Differences in General Cognitive Abilities and Domain-Specific Skills of Higher-and Lower-Achieving Students in Stoichiometry. *Journal of Chemical Education, 91*(7), 961-968.

Hein, S. M. (2012). Positive impacts using POGIL in organic chemistry. *Journal of Chemical Education, 89*(7), 860-864.

Janssen, J., Kirschner, F., Erkens, G., Kirschner, P. A., & Paas, F. (2010). Making the black box of collaborative learning transparent: Combining process-oriented and cognitive load approaches. *Educational Psychology Review, 22*(2), 139-154.

Johnstone, A. H. (1997). Chemistry teaching – Science or Alchemy? *Journal of Chemical Education, 74*, 262-268.

Johnstone, A. H. (2006). Chemical education research in Glasgow in perspective. *Chemistry Education Research and Practice, 2*, 49-63.

Johnstone, A. H. (2010). You can't get there from here. *Journal of Chemical Education, 87*, 22-28.

Johnstone, A. H., & Selepeng, D. (2001). A language problem revisited. *Chemistry Education Research and Practice, 2*(1), 19-29.

Johnson, D. W., & Johnson, R. T. (2009). An educational psychology success story: Social interdependence theory and cooperative learning. *Educational Researcher, 38*(5), 365-379.

Kaundjwa, A. O. (2015). *Influence of process oriented guided inquiry learning (POGIL) on Science Foundation students' achievements in stoichiometry problems at the University of Namibia*. Unpublished PhD dissertation, University of South Africa.

Kirby, N., & Dempster, E. (2011). The (re) construction of a philosophical and pedagogical position for the Foundation Programme at UKZN with particular reference to the Biology module. *South African Journal of Higher Education, 25*(6), 1103-1124.

Moog, R. (2014). Process oriented guided inquiry learning. In M. A. McDaniel, R. F. Frey, S. M. Fitzpatrick, & H. L. Roediger III (Eds.), *Integrating cognitive science with innovative teaching in STEM disciplines.* (pp. 147-166). St Louis: Washington University Libraries.

Moog, R. S., & Farrell, J. J. (2008). *Chemistry, A Guided Inquiry* (4th ed.). New York: John Wiley.

Ogude, N. A., Kilfoil, W., & Du Plessis, G. (2012). An institutional model for improving student retention and success at the University of Pretoria. *International Journal of the First Year in Higher Education, 3*(1), 21-34.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist, 38*(1), 1-4.

Piaget, J. (1964). Part I: Cognitive development in children: Piaget development and learning. *Journal of Research in Science Teaching, 2*(3), 176-186.

Potgieter, M., & Davidowitz, B. (2010). Grade 12 achievement rating scales in the new National Senior Certificate as indication of preparedness for tertiary chemistry. *South African Journal of Chemistry, 63*, 75-82.

Pym, J. (2013). From fixing to possibility: Changing a learning model for undergraduate students. *South African Journal of Higher Education*, *27*(2), 353-367.

Reid, N. (2008). A scientific approach to the teaching of chemistry. What do we know about how students learn in the sciences, and how can we make our teaching match this to maximise performance? *Chemistry Education Research and Practice, 9*(1), 51-59.

Shay, S., Wolff, K., & Clarence-Fincham, J. (2016). Curriculum reform in South Africa: more time for what? *Critical Studies in Teaching and Learning, 4*(1), 74-88.

Stronge, J. H. (2018). *Qualities of effective teachers.* Virginia: ASCD.

Sweller, J., Van Merrienboer, J. J., & Paas, F. G. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, *10*(3), 251-296.

Treagust, D. F., Qureshi, S. S., Venkat, R. V., Ojeil, J., Mocerino, M., & Southam, D. C. (2018). Process-Oriented Guided Inquiry Learning (POGIL) as a Culturally Relevant Pedagogy (CRP) in Qatar: a Perspective from Grade 10 Chemistry class. *Research in Science Education*, 1-19.