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Active versus passive learning: Comparative case study of problem-solving competencies in stoichiometry

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Abstract

Teaching methods can help learners to develop problem-solving skills and enhance their achievement in stoichiometry. Process oriented guided inquiry learning (POGIL) is one of the teaching methods that promote problem-solving skills because it provides opportunities for learners to work with many formulae through many steps in solving problems such as stoichiometric calculations of number of moles and concentration of solutions. To understand how POGIL can improve learners' achievement and develop problem-solving skills, four grade 11 physical sciences classes of mixed gender and multicultural black learners were purposefully and conventional sampled from four different township schools in Pretoria, South Africa. Through pre- and post-test case study and lesson observations, two different independent groups (POGIL group and lecture group) were included in the study. POGIL group constituted 48 students, while lecture group 62 students taught by their respective teachers at their schools for three weeks using English second language. The results from the pre-test suggest that learners in all the four classes lacked problem-solving competencies in solving both the low-order and the high-order stoichiometry questions. According to the research interpretation, lesson observations of POGIL were active learning while lecture method was passive learning. The post-test results indicate statistically significant greater problem-solving competencies in POGIL group than in the lecture group. The study recommends the use of POGIL in teaching stoichiometry.

Keywords: process oriented guided inquiry learning, stoichiometry, active learning, problem-solving competency, lecture method

INTRODUCTION

South African (SA) learners demonstrated challenges in stoichiometry on topics such as the mole concept, the quantities of products and reactants, and the limiting reactants (Department of Basic Education [DoBE], 2019). Competence in stoichiometry calculations challenges both teachers and learners (Stott, 2021). SA teachers without bachelors' degree focus on algorithm calculations and less on conceptual understanding (Stott, 2020). SA learners have misconceptions and fear in answering stoichiometry questions (Booi, 2023; Miheso & Mavhunga, 2020).

SA university students fail to balance equations of reactions and identify the limiting reactant and the reaction yield (Marais & Combrinck, 2009). For this reason, teacher education in SA ought to focus on competencies in solving calculations and proportions (Stott, 2021). Therefore, the development of in-service teacher programs to enhance the teaching of stoichiometry is recommended to mitigate the deficiencies in teaching stoichiometry and chemistry (Malcolm et al., 2019; Stott, 2021). Use of inquiry methods such as process oriented guided inquiry learning (POGIL) reduce misconceptions in stoichiometry (Mamombe et al., 2021). One of the approaches is to use sub-micro diagram, which is

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Contribution to the literature

- The study is set in a specific cultural and educational context, offering insights into the challenges and successes of implementing active learning strategies in South African township schools. This adds to the literature on educational reforms and teaching methodologies in diverse international contexts.
- By employing both quantitative and qualitative methods, the study provides a comprehensive analysis of the impact of teaching methods on student learning outcomes. This mixed-methods approach enriches the literature by showing not only the effectiveness of POGIL but also the classroom dynamics and student engagement patterns that contribute to learning outcomes.
- This study provides a detailed case study of how innovative teaching methodologies can improve learning outcomes in specific scientific disciplines and educational settings, thereby supporting calls for broader educational reforms that embrace active learning.

believed can improve university students' understanding of stoichiometry (Davidowitz et al., 2010).

Elsewhere, similar challenges in stoichiometry have been observed. Zimbabwean high school learners presented similar challenges in solving stoichiometry (Mandina & Ochonogor, 2018). Use of simulations increased conceptual understanding of stoichiometry in Lesotho (Mohafa et al., 2022). Nigerian learners taught using problem-solving techniques performed statistically significantly better than those taught using the lecture method (Sunday et al., 2019). It appears that the use of active teaching methods may alleviate the challenges of conceptual understanding, problem-solving skills, and misconceptions.

The current approach is POGIL, which is a learner-centered problem-solving strategy, where learners collaboratively solve worksheets in small teams of three, four, or five (Simonson, 2019). The learners work from the familiar, too simple, and then complex constructs helping them solve abstract problems under the guidance of teachers who are acting as facilitators (Moog & Spencer, 2008). POGIL worksheets are developed to follow a learning cycle (Lawson, 1988). The current study compared POGIL and lecture methods on learners' problem-solving competencies in stoichiometry. In the context of this study problem-solving competency is the learner's ability to successfully solve both simple and complex stoichiometry problems (Bodner & Herron, 2002). POGIL has been observed to increase SA high school learners' understanding and achievement of stoichiometry (Mamombe et al., 2021). Students who were taught design patterns using POGIL improved critical thinking, problem-solving, and communication skills (Lotlikar & Wagh, 2016), making POGIL a statistically significantly more effective approach in teaching practical chemistry than the lecture method (Omoniyi & Torru, 2019).

SA curriculum and assessment policy statement (CAPS) recommends science teachers use investigative methods (DoBE, 2012), but SA teachers commonly use the lecture method in science (Bantwini, 2017; Dudu, 2014; John, 2019).

The current study was a pre- and post-test comparative study of the effectiveness of POGIL and lecture method on grade 11 learners' problem-solving competencies in stoichiometry.

The main research question was, as follows:

1. What is the effect of teaching approach on learners' problem-solving competencies in stoichiometry?

The sub research questions were, as follows:

a. What is the relationship between learners' problem-solving competencies in stoichiometry in POGIL group compared to the lecture group before the intervention?
b. What is the relationship between learners' problem-solving competencies in stoichiometry in POGIL group compared to the lecture group after the intervention?
c. How did the classroom activities of both teachers and learners in POGIL classes compare to the lecture classes?

The current study focused on comparing, quantitatively, the problem-solving competencies of learners in POGIL group to those in the lecture group after instruction. The study further analyzed the difference in problem-solving competencies by evaluating the learners' activities during the lessons. The current study was guided by interactive-constructive-active-passive (ICAP) framework, which assessed the learners' engagement during lessons.

LITERATURE REVIEW

Challenges experienced by SA high school learners in the chemistry section of physical sciences have been observed and documented (DoBE, 2020). SA high school learners have demonstrated misconceptions about the dissolution of salts (Kibirige et al., 2014), force (Kibirige & Mamashela, 2022), and stoichiometry (Stott, 2021). University students in SA have demonstrated limitations in stoichiometry, particularly the symbols and balancing of chemical equations (Marais & Combrinck, 2009). Elsewhere, Indonesian, and Thai learners demonstrated misconceptions in stoichiometry, particularly indicators, the mole concept, and limiting reactants (Dahsah & Coll, 2007; Saadah et al., 2022). High school learners in Turkey equally demonstrated challenges in chemical representations using symbols (Celikkiran, 2020).

The challenges of learners in stoichiometry seem to be universal, hence the need for addressing these by using alternative teaching methods.

Use of POGIL improved learning outcomes in American learners (Hu et al., 2016) and equally improved SA learners' understanding of stoichiometry (Mamombe et al., 2021). Learners' achievement in stoichiometry is directly related to their mathematical problem-solving skills and conceptual understanding (Owoyemi & Amahwe, 2020). The use of problem-solving instruction was effective in remedying learners' difficulties in stoichiometry (Mandina & Ochonogor, 2018).

Lesotho science teachers demonstrated lack of effective pedagogical skills in stoichiometry (Makhechane & Qhobela, 2019). Stoichiometry has challenged learners of different nationalities and teachers alike, even though teacher development programs have been crafted to assist teachers in the teaching of stoichiometry (Malcom et al., 2019).

POGIL method promotes active engagement of learners (Strachan & Liyanage, 2015). Use of active engagement may result in improved conceptual understanding (Simonson, 2019). POGIL, therefore, may impact cognitive development of learners as they invent concepts and develop understanding (Moog & Spencer, 2008).

The collaborative teams in POGIL classes may provide platform for teamwork, whereby learners assist each other (Simonson & Shadle, 2013). For this reason, the learners taught using POGIL may improve problem-solving skills and other process skills like communication, and critical thinking, among others (Moog & Spencer, 2008; Simonson & Shadle, 2013). While some teaching methods may partially develop learners to solve simple calculations, POGIL may lead to learners solving both simple and complex questions (Simonson, 2019). This has a direct impact on improving motivation and achievement of the learners (Santoso et al., 2023).

CONCEPTUAL FRAMEWORK

An ICAP framework guided this study (Chi et al., 2018). ICAP framework is a constructivist theory, which defines cognitive engagement activities based on students' overt behaviors. It proposes that engagement behaviors can be classified into four modes of engagement, which are interactive, constructive, active, and passive engagements. During 'constructive engagement' learners individually construct knowledge by writing own notes, drawing a concept map, predicting, inventing, or self-evaluating one's own ideas (Simonson, 2019).

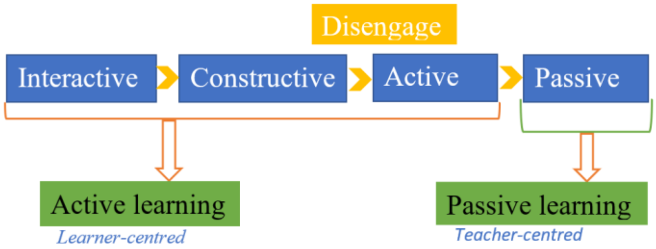

Figure 1. ICAP theory of active learning (Chi et al., 2018)

The 'interactive engagement' is when two or more learners collaboratively elaborate, justify, explain, question each other's ideas, and add-on to each other's idea until they reach consensus. Both the 'interactive' and 'constructive modes' of engagement involve information processing and problem solving. 'Active engagement' is associated with manipulative skills such as pointing to, or gesturing, repeating, copying, rehearsing, underlining, or choosing. 'Passive engagement' is when learners are listening to instructions, reading a text silently, or watching a video, without undertaking any visible activities. The 'passive mode' of engagement involves low order thinking skills. When learners are doing what they are expected to do in the interactive, constructive, active, or passive modes, they are in the 'engaged mode'. If they do other activities apart from the assigned task they are in the 'disengaged mode' (Chi et al., 2018).

ICAP framework defines the combination of the interactive, constructive, and active modes as "active learning modes". Active learning is associated with learner-centered teaching methods such as POGIL, where learners are engaged in activities that are guided by a learning cycle (Lawson, 1988).

Passive learning is associated with teacher-centered methods like lectures. However, during active learning methods, there are moments when learners are passive and sometimes disengaged. On the other hand, in passive learning methods, there are moments when learners may be engaged in the active mode of learning. Therefore, modes of cognitive engagement during active and passive learning methods may overlap. **Figure 1** shows a simplified drawing of ICAP framework.

Thus, ICAP framework, as applied in this study, was used to differentiate learners' modes of cognitive engagement during both POGIL and the lecture lessons. This seemed ideal in monitoring cognitive engagements through the activities of the learners in both the lecture and POGIL classes. Since POGIL is associated with group activities, we assumed the learners' cognitive engagement would be in the "active learning modes".

The lecture method is associated with learners listening to the teacher and taking notes thereby classifying the learners' cognitive engagement in the "passive learning mode". The use of pre- and post-test was justified on the basis that all learners answered individually. This defined their 'constructive' mode of engagement.

METHODOLOGY

This mixed method case study compared the effects of a POGIL method and lecture method on learners' problem-solving competencies in stoichiometry tests. A mixed method case study design involves both quantitative and qualitative data collection, analysis, and integration to provide in-depth evidence (Creswell & Clark, 2018). Qualitative data was obtained from observing the learners' engagements during the respective lessons. Quantitative data was obtained from the learners' scores in pre- and post-test.

Sampling

The two teachers who participated in POGIL classes were part of the 25 high school science teachers from a district in Pretoria who participated in a three-day POGIL intervention workshop. This was a professional development workshop facilitated by one university to promote the use of POGIL in schools. These two teachers volunteered to teach stoichiometry to one of their grade 11 physical science classes using POGIL at their respective schools. For POGIL classes, 22 learners at school A and 26 learners at school B consented to participate in the study. The lecture classes comprised 28 learners at school C and 34 learners at school D alongside their respective science teachers. The teachers at schools C and D were unfamiliar with POGIL and used the lecture method in their classes.

Test Instruments

The questions in both pre- and post-test were similar except for differences in the amounts of substances. The questions were set on a continuum of levels of complexity as prescribed in CAPS curriculum by DoBE (2012). The current study was done in SA, where CAPS curriculum serves many of the candidates at both primary and secondary school. CAPS curriculum also prescribes assessment strategies for questions in the formal tests and examinations.

Data Collection

Data were collected using pre- and post-test and lesson observations. The data collection process started with a pre-test, followed by lesson observations, and concluded with the post-test.

Pre- & post-test

Pre- and post-test were similarly designed by adapting the physical sciences examination questions of CAPS curriculum (DoBE, 2012). These tests were initially validated by two senior physical science teachers and two teacher education lecturers. The learners were instructed to answer all questions in full, by showing all the necessary formulae, calculations, and ending with the answer. They were reminded that there were marks allocated for each of these parts of the calculations. The one-hour pre-test was administered by the respective subject teachers during mid-week at their respective schools.

During the third week after the intervention the teachers administered the one-hour post-test to the learners at their respective schools. Both pre- and post-test were composed of ten items of different levels of complexities (see **Appendix A** and **Appendix B**). The design on both pre- and post-test were guided by CAPS syllabus, which classifies questions into levels of complexity.

A level I question elicits a definition, a law, or a single-step calculation requiring only one formula. A single step entailed selection of a correct formula, appropriate substitution, and getting the correct answer. A level II question elicits a calculation, which requires a two-step calculation and the use of two formulae. A level three question demands a three-step calculation using three formulae, while a level four question is the most complex question requiring the use of four steps and four formulae (DoBE, 2012). These classifications are related to Bloom's taxonomy of cognitive domains, where a level I question expects recall of basic facts, level II requires understanding, where the learner interprets, and discusses facts. Level III demands analysis and application of knowledge, while level IV expects evaluation and synthesis of ideas (McGuire & McGuire, 2015). **Table 1** shows the design of the questions in pre- and post-test.

Lesson observation

The second stage of data collection after the pre-test was the intervention using POGIL method (experimental group) and the lecture method (control group). The lessons were designed using CAPS syllabus (DoBE, 2012). The intervention lessons were taught by the usual teachers of the sampled classes. Two teachers who were previously trained to teach using POGIL taught one of their classes using the said teaching method. Another two teachers from a different district, who were not trained to teach using POGIL used the lecture method. All the four lessons, which were one hour long were observed by the researcher using the observations schedules (see **Table 2**) and for learners (see **Table 3**).

Table 1. Structure of questions in pre- & post-test

Q&L	Bloom's cognitive levels	Skills assessed
1-I	Remembering	Identify correct formula. Substitute in the formula, identify the correct atomic mass.
2-III	Analyze & apply	Choose correct formula & substitute appropriately. Link two formulae using mole ratio.
3a-III	Analyze & apply	Choose correct formula & substitute appropriately. Link two formulae using mole ratio.
3b-II	Understanding	Use balanced equation of reaction & mole ratio, substitute appropriately, & calculate final answer.
4a-I	Remembering	Remember definition of a limiting reactant.
4b-IV	Analyze, apply, create, & evaluate	Choose correct formula & substitute appropriately. Use mole ratio from a balanced chemical reaction to link formulae.
5-IV	Analyze, apply, create, & evaluate	Calculate molecular mass of three compounds, convert cm^3 to dm^3, choose correct formula & substitute appropriately. Use mole ratio to calculate & compare number of moles.
6a-II	Understanding	Count the number of atoms of each element. Compare both sides of equation. Balance equation using a suitable coefficient.
6b-II	Understanding	Use appropriate ratio, choose correct formula, substitute appropriately, & calculate answer.
6c-II	Understanding	Use appropriate ratio, choose correct formula, substitute appropriately, & calculate answer.

Note. Q&L: Question & level

Table 2. Observation schedule for teachers' activities

POGIL lessons	Lecture lessons
Provide worksheets (resources)	Read for learners
Give directions	Give instructions
Supervise class	Play video
Ask probing questions	Explain concepts
Manage time	Dictate notes
Guide learners	Solve problems
Pose problems	Give examples
Ask learners to discuss	Instruct learners to copy
Correct misconceptions	Instruct learners
Ask learners to assess themselves	Assess learners
Ask learners to clarify concepts	Clarify concepts
Appoint learners to solve problems	Solve problems
Assign a learner to conclude activity	Conclude activity

Table 3. Observation schedule for learners' activities

Interactive	Constructive	Active	Passive	Disengage
Ask one other	Draw concept map	Repeat	Listen to reader	Doing other things
Discuss	Predict	Copy	Read a text silently	Daydreaming
Justify	Invent ideas/notes	Rehearse	Watch a video	Other discussions
Explain	Argue	Underline	Listen to teacher	
Evaluate	State hypothesis	Choose	Take down notes	
Elaborate	Self-evaluate	Build object		
Challenge	Explain			
Build-on	Justify			
Ask teacher				

Both POGIL and lecture lessons were conducted at respective schools during weekends to avoid disrupting the normal programs of the schools. Teachers in the lecture classes were allowed to prepare their own lessons plans so that they could teach as they usually did guided by CAPS document. Teachers in POGIL classes used pre-existing POGIL worksheets (from www.pogil.org). POGIL worksheets were adapted to SA context by using familiar examples and adhering to the aims and objectives of CAPS syllabus. The learners in both POGIL and lecture classes were taught for a total of four hours divided into two lessons each weekend. During each weekend there were short breaks between the lessons for both POGIL and lecture groups.

To assess the approach used by the teachers, the researcher observed all lessons using observation schedules for teachers (see **Table 2**) and learners (see **Table 3**). The observation schedule for teachers was designed to establish the teaching approach in adherence to the roles of the teacher with reference to ICAP framework (Chi et al., 2018).

The observation schedule for the teachers on **Table 2** was used by making a tally after the occurrence of the teacher's activities in a period of two minutes. The tallies were recorded every two minutes for the four-hour duration of the lessons. These were recorded during both POGIL lessons and the lecture lessons and were used to define the teaching approach used.

The observation schedule for the learners focused on learners' activities to establish their cognitive engagement in relation to ICAP framework (Chi et al., 2018). It was important to focus on learners' engagement to ascertain their cognitive development arising from the teaching approach used. **Table 3** shows the observation schedule used for the observation of learners during the lessons. When an action was observed over two consecutive minutes a tally was allocated. In POGIL classes the learners were in teams of four. The observer recorded the group activity since learners in each group coordinated their actions. Learners' actions in the lecture classes were coordinated by the teacher. For that reason, most of the records during the lecture lessons represented the actions of the class.

Data Analysis

Data analysis entailed the interpretation of the data collected using the tests and the lesson observations.

During intervention

The teachers' activities as indicated on **Table 3** assisted in the classification of the lesson as POGIL or lecture. The teachers' and the learners' activities were guided by ICAP framework and assisted in data analysis to answer the third sub-research question. The assessment of the actions of the learners translated into the level of cognitive engagement of the learners during the lessons and was facilitated by scaling the learners' activities. The learners' activities were classified according to 'interactive', 'constructive', 'active', 'passive', or 'disengaged' (see **Table 4**). When the learners discussed the same topic the mode of engagement was recorded as 'interactive' mode. When learners individually brainstormed by putting together their ideas before discussing with their peers the mode of engagement was recorded as 'constructive'. The 'active' mode of engagement entailed manipulative activities such as copying, drawing, underlining, or choosing. The learners' engagement was 'passive' mode when they listened to instructions, read a text, without undertaking any visible activities. The learners' mode of engagement was 'disengaged' when the learners did other activities, which had nothing to do with the assignment.

During tests

Both pre- and post-test were assessed by analyzing the correctness and the number of completed steps in the response. The complexity of the question (see **Table 1**) determined the classification of the learners' answers (see **Table 4**). A response was classified as 'novice' if in any type of question there was no response (blank) or there was no single step calculation completed.

An answer was classified as 'elementary' if there was a correct definition or only one step calculation to any type of question. An 'intermediate' answer entailed a response, where two steps were fully completed on a levels II, III, or IV question because it was impossible to have two-steps on a level I question. An answer was classified as 'competent' when three steps were correctly executed in response to a level III or level IV question. It was impossible to have three steps on either level I or level II questions. An answer was classified as 'advanced' when four steps were correctly followed in response to a level IV question. It was impossible to get four steps on level I, II, or III questions. The learners' problem-solving competencies were entailed by the level of the classification of their answer. The learners' scripts were coded initially by the primary researcher and then by the second author. The two coders discussed and reached consensus on the coding.

Table 4. Classification of responses to questions in tests

QL	Number of correct steps	Response classification
I	0	'Novice'
	1	'Elementary'
II	0	'Novice'
	1	'Elementary'
	2	'Intermediate'
III	0	'Novice'
	1	'Elementary'
	2	'Intermediate'
	3	'Competent'
IV	0	'Novice'
	1	'Elementary'
	2	'Intermediate'
	3	'Competent'
	4	'Advanced'

Note. QL: Question level

Table 4 summarizes the classification of responses relative to the question level.

For the purposes of recording the test scores, a 'novice' response was allocated zero points because there was nothing achieved by the learner, an 'elementary' response was allocated one point because the learner completed one step, and an 'intermediate' response was allocated two points because the learner completed two steps. A 'competent' and an 'advanced' response were, for the same reason, allocated three and four points, respectively. The higher the sum of the test scores attained by an individual or class, the higher the competency.

Statistical data analysis was done on the quantitative data from pre- and post-test scores. Descriptive statistics were done to describe the data of both pre- and post-test. Similarities, trends, and differences were identified and to further analyze both pre- and post-test quantitative data about the learners' competencies in stoichiometry inferential statistics was used. Two hypotheses were proposed.

H_0 There is no relationship between the learners' problem-solving competencies and the teaching approach.

Table 5. Results of observation of a POGIL lesson

Level	Interactive	Constructive	Active	Passive	Disengage
Frequency	68	24	8	17	3
Percentage	57%	20%	7%	14%	3%

H_1 There is a relationship between the learners' problem-solving competencies and the teaching approach.

The null and alternative hypotheses were used to guide the study by comparing the problem-solving competencies of the learners in the two groups before and after the intervention. Analysis of variance (ANOVA) test was found ideal to use to analyze the test scores of the two groups.

ANOVA test was ideal for this study because there was only one independent variable (teaching approach) and only one dependent variable, which was learners' problem-solving competencies.

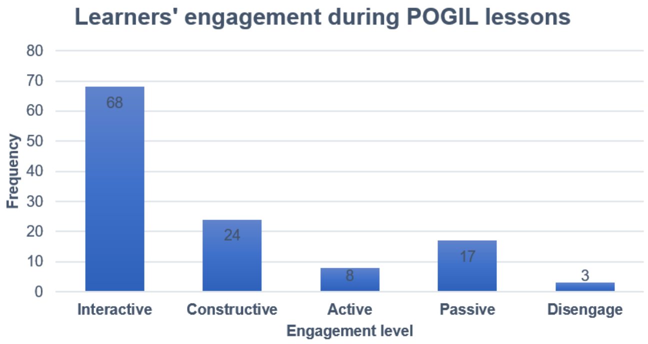

Figure 2. Learners' engagement during POGIL lessons (Source: Authors' own elaboration)

RESULTS

To address the qualitative section of the study, the lesson observations, learners' activities during lessons, examples of learners' responses in pre- and post-test were discussed. Qualitative data was aimed to answer the third research question. To address the results of the quantitative data descriptive and inferential statistics were used where appropriate. Quantitative data was used to answer the first and second sub-research questions.

Qualitative Data

The activities of both the teachers and the learners were used to provide qualitative data about how these activities may have influenced the test scores. The third sub-research question was, as follows:

How did the classroom activities of both teachers and learners in POGIL classes compare to the lecture classes?

The report of the results shall commence with what was observed during the lessons.

Learners' activities during POGIL lessons

Table 4 was used to record the learners' activities to classify the level of engagement. As described in the data collection section the records were taken after every two minutes. **Table 5** shows the results of the observation of one of POGIL lessons. The results from the other POGIL class were like these recorded on **Table 5**. Results from observation of POGIL lessons comply with expectations of POGIL lessons in terms of the learners' activities.

The learners were in the 'interactive' mode for 57% of the duration of the lesson and in the 'constructive' mode for 20% of the duration of the lesson. The 'active' mode occupied 7% of the lesson, while the 'passive and 'disengaged' modes occupied 14% and 3% of the duration of POGIL lessons, respectively. During POGIL lessons the results indicate a large percentage of 'interactive' and 'constructive' engagement as clearly shown on **Figure 2**. The learners were actively engaged for 74% of the duration of the lesson.

There were few moments where the learners were in 'disengaged' mode. The learners were in the 'passive' mode for considerable time. These lessons were noisy as the learners deliberated the activities in the worksheets.

Teacher's activities during POGIL lessons

During POGIL lessons the teacher guided the learners by asking probing questions without telling the learners the answers. The teacher provided the worksheets and monitored the timeous completion of each activity. The teacher asked the spokespersons of each group to report their answers to the class. This was followed by discussion by the class to determine the correctness of the answers. The teacher moderated the discussion and only elaborated, where learners had disagreements or misconceptions. The teacher's activities comply with the expectations of POGIL facilitation.

Learners' activities during lecture lessons

The activities of the learners during the lecture lessons were classified using **Table 4**. **Table 6** shows the results from one of the lecture classes. The second lecture class expressed similar results. We have used results from one of the classes for the purposes of discussion.

As indicated on **Table 6** the 'interactive' and the 'constructive' modes witnessed 2% and 15%, respectively. The learners were in the 'active' and 'passive' mode for 28% and 60% of the duration of the lessons, respectively. The learners were in 'disengaged' mode for 5% of the duration of the lessons. The learners in the lecture lessons witnessed a large percentage of 'passive' and 'active' engagement as shown in **Figure 3**.

Table 6. Results of observation of a lecture lesson

Level	Interactive	Constructive	Active	Passive	Disengage
Frequency	2	18	34	60	6
Percentage	2%	15%	28%	50%	5%

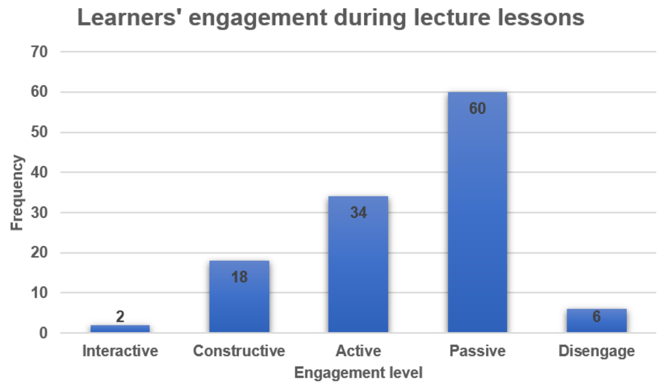

Figure 3. Learners' engagement during lecture lessons (Source: Authors' own elaboration)

Teacher's activities during lecture lessons

During the lecture lessons the teacher explained all the concepts and gave notes to the learners who quietly paid attention. The teacher used examples and solved them for the learners who continued to copy in their notebooks. The teacher did all the talking with a few questions posed to the learners. The teacher did not pay much attention to the responses of the learners to their questions but continued to explain the concepts. The activities of the teachers were classified using Table 3 and showed that lecture method was appropriately used.

Quantitative Data

To answer the first and second sub-research question quantitative data were collected and analyzed as indicated in the data collection and analysis sections.

The first sub-research question asked:

What is the relationship between learners' problem-solving competencies in stoichiometry in POGIL group compared to the lecture group before the intervention?

The second sub-research question asked, as follows:

What is the relationship between learners' problem-solving competencies in stoichiometry in POGIL group compared to the lecture group after the intervention?

Descriptive statistics of pre-test results

To answer the first sub-research question descriptive statistics were used for both POGIL group and the lecture group in pre-test.

Even though all learners were taught stoichiometry using the lecture method in the previous grade, most learners in all the classes demonstrated 'novice' ideas in the pre-test. Some learners left the questions unanswered, others failed to identify the correct formula while the remainder could not recall the definition of a limiting reactant. Most learners failed to attempt the multi-step calculations. Table 7 shows the pre-test results for both groups.

No learner in all four classes demonstrated 'advanced' competency to solve stoichiometry problems, while a few demonstrated 'competent' competency. The percentage of learners with 'intermediate' competency was 5% and 4% in POGIL group and the lecture group, respectively. The percentage of learners with 'elementary' competency was 26% in POGIL group compared to 28% in the lecture group. The percentage of learners with 'novice' competency were 68% and 67% in POGIL and lecture groups, respectively. The results indicate that learners' problem-solving competencies in the pre-test in both groups were comparable. There was, therefore, no need to perform inferential statistics of the pre-test results.

Table 7. Pre-test results

Question	Advanced		Competent		Intermediate		Elementary		Novice	
	POGIL	Lecture	POGIL	Lecture	POGIL	Lecture	POGIL	Lecture	POGIL	Lecture
1							35	20	13	42
2			2	1	2	2	7	20	37	39
3(a)			3	2	2	5	9	12	34	43
3(b)					3	3	9	16	36	43
4(a)							12	16	36	46
4(b)	0	0	1	0	3	2	7	20	37	40
5	0	0	4	3	6	6	9	18	29	35
6(a)					6	2	7	16	35	44
6(b)					0	2	15	17	33	43
6(c)					0	3	13	18	35	41
Total	0	0	10	6	22	26	123	172	325	416
Percentage	0%	0%	2%	1%	5%	4%	26%	28%	68%	67%

Table 8. Post-test results

Question	Advanced		Competent		Intermediate		Elementary		Novice	
	POGIL	Lecture	POGIL	Lecture	POGIL	Lecture	POGIL	Lecture	POGIL	Lecture
1							47	35	1	27
2			35	6	6	11	5	15	2	30
3(a)			36	5	8	9	4	20	0	28
3(b)					27	7	15	22	6	33
4(a)							42	25	6	37
4(b)	6	2	28	5	11	8	0	17	3	30
5	18	3	18	4	4	10	3	18	5	27
6(a)					23	8	17	21	8	33
6(b)					32	3	5	19	11	40
6(c)					25	8	4	17	19	37
Total	24	5	117	20	136	64	142	209	61	322
Percentage	5%	1%	24%	3%	28%	10%	30%	34%	13%	52%

Descriptive statistics of post-test results

To answer the second sub-research question descriptive statistics were done to assess the relationship between learners' post-test problem-solving competencies in stoichiometry in POGIL group compared to the lecture group after the intervention.

The post-test results suggest that learners in both POGIL and lecture classes improved in solving stoichiometry questions. Some of the learners managed to solve the simple and even some multi-step calculations. The improvement of POGIL classes, however, seemed higher than that of the lecture classes. **Table 8** shows the post-test results for POGIL and lecture classes. The lecture classes evinced a high number of 'novice' ideas in all the questions compared to POGIL classes. The number of 'advanced', 'competent', and 'intermediate' ideas were higher in POGIL classes than in the lecture classes.

Level I Questions

Questions 1 and 4a

Questions 1 and 4a were level I questions asking learners to recall a definition or complete single-step calculation. In POGIL group in question 1 there was only one 'novice' response (2%) compared to 27 responses (44%) in the lecture group. In question 4a there were six 'novice' responses (13%) in POGIL group compared to 37 responses (60%) in the lecture group. The rest of the responses were acceptable 'elementary' knowledge in solving the level 1 question. It implies that in the level 1 questions learners in POGIL classes performed better than those in the lecture classes.

Level II Questions

Questions 3b, 6a, 6b, and 6c were level II requiring responses through two-step calculations. In question 3b POGIL group had 27 'intermediate' responses (56%), 15 'elementary' responses (31%), and six 'novice' responses (13%). The lecture group had seven 'intermediate' responses (11%), 22 'elementary' responses (35%), and 33 'novice' responses (53%) in the same question. In question 6a there were 23 'intermediate' responses (48%), 17 'elementary' responses (35%), and eight 'novice' responses (17%) in POGIL group. This was compared to eight 'intermediate' responses (13%), 21 'elementary' responses (34%), and 33 'novice' responses (53%) in the lecture group.

Question 6b had 32 'intermediate' response (67%), five 'elementary' responses (10%) and 11 'novice responses (23%) in POGIL group. In contrast the lecture group had three 'intermediate' responses (5%), 19 'elementary' responses (31%), and 40 'novice' responses (65%).

Question 6c elicited 25 'intermediate' responses (52%), four 'elementary' response (8%), and 19 'novice' responses (40%) in POGIL group. This was compared to eight 'intermediate' responses (13%), 17 'elementary' response (27%), and 37 'novice' responses (60%) in the lecture group.

The results of the level II questions show that learners in POGIL classes had better problem-solving competencies than those in the lecture classes. POGIL group had more 'intermediate' responses than the lecture group. The lecture group witnessed more 'novice' and 'elementary' responses than POGIL group.

Level III Questions

Level III questions 2 and 3a required answers through three steps. In POGIL group, question 2 elicited 35 'competent' responses (73%), six 'intermediate' responses (13%), five 'elementary' responses (10%), and two 'novice' responses (4%). The lecture group, on the other hand, reported six 'competent' responses (10%), 11 'intermediate' responses (18%), 15 'elementary' responses (24%), and 30 'novice' responses (48%).

Question 3a in POGIL group obtained 36 'competent' responses (75%), eight 'intermediate' responses (18%), four 'elementary' responses (8%), and no 'novice' responses. In the same question, the lecture group had five 'competent' responses (8%), nine 'intermediate' responses (15%), 20 'elementary' responses (32%), and 28 'novice' responses (45%).

The higher percentages of 'competent' and 'intermediate' responses of POGIL classes from the level III questions suggest that the learners in POGIL group had better problem-solving competencies than their counterparts in the lecture group.

Level IV Questions

Level IV questions 4b and 5 required responses through four steps. In POGIL group question 4b generated six 'advanced' responses (13%), 26 'competent' responses (58%), 11 'intermediate' responses (23%), no 'elementary' responses, and three 'novice' responses (6%). Lecture group had two 'advanced' responses (3%), five 'competent' responses (8%), eight 'intermediate' responses (13%), 17 'elementary' responses (27%), and 30 'novice' responses (48%).

Question 5 in POGIL group elicited 18 'advanced' responses (38%), 18 'competent' responses (38%), four 'intermediate' responses (8%), three 'elementary' responses (6%), and five 'novice' responses (10%). The lecture group had three 'advanced' responses (5%), four 'competent' responses (6%), 10 'intermediate' responses (16%), 18 'elementary' responses (29%), and 27 'novice' responses (44%).

The results from the level IV questions suggest that the learners in POGIL group had better problem-solving competencies than their counterparts in the lecture group. Overly in the post-test, the learners in POGIL group showed better problem-solving competencies in solving stoichiometric problems than the learners in the lecture group.

The null hypothesis was, therefore, rejected since the results suggest that there is a relationship between the learners' problem-solving competencies and the teaching approach. In this case, POGIL method developed higher problem-solving competencies than the lecture method. The learners in POGIL group solved both simple and complex questions, while the learners in the lecture group had difficulties in solving both simple and multi-step calculation questions alike.

ANOVA Tests

The data from the post-test verified some distinctions in problem-solving competencies of POGIL and the lecture groups. For that reason, ANOVA tests were performed for the post-test results of the lecture group compared to POGIL group. The purpose of the ANOVA test was to find out if teaching approach statistical significantly affected the learners' competencies in stoichiometry. **Table 9** shows the results of the effect of the change in the teaching method as measured in the learners' responses to the post-test.

The results, as shown in **Table 9**, indicate all p-values lower than alpha (0, 05) in all the questions. Such results confirm that there was a statistical difference in the learners' problem-solving competencies between the two groups. Further analysis indicates that in all the questions, the averages, and the sums of POGIL group were higher than the lecture group. The higher the test scores the higher the competencies, as shown in **Table 5**. Therefore, the problem-solving competencies of learners in POGIL group were statistically significantly higher than learners in the lecture group.

DISCUSSION

In this paper, we found out that the lecture method, which is widely used by teachers in secondary schools in SA and universities alike, does not pay attention to the active engagement of learners. Some reasons for

Table 9. Post-test results in lecture compared to POGIL group

Question	Count	Sum	Average	Variance	Source of variation	SS	df	MS	F	p-value
Q1 Lecture	62	35	0.564516	0.249868	Between groups	4.651625	1	4.651625	30.97049	1.93E-07
Q1 POGIL	48	47	0.979167	0.020833	Within groups	16.221100	108	0.150195		
Q2 Lecture	62	55	0.887097	1.052618	Between groups	74.064570	1	74.064570	81.51708	7.49E-15
Q2 POGIL	48	122	2.541667	0.721631	Within groups	98.126340	108	0.908577		
Q3a Lecture	62	52	0.838710	0.924379	Between groups	90.400780	1	90.400780	130.0839	2.98E-20
Q3a POGIL	48	128	2.666667	0.397163	Within groups	75.053760	108	0.694942		
Q3b Lecture	62	36	0.580645	0.476996	Between groups	19.863450	1	19.863450	40.54588	4.79E-09
Q3b POGIL	48	69	1.437500	0.506649	Within groups	52.909270	108	0.489901		
Q4a Lecture	62	25	0.403226	0.244580	Between groups	6.021554	1	6.021554	32.24336	1.16E-07
Q4a POGIL	48	42	0.875000	0.111702	Within groups	20.169350	108	0.186753		
Q4b Lecture	62	55	0.887097	1.249339	Between groups	68.574790	1	68.57479	52.82929	6.02E-11
Q4b POGIL	48	119	2.479167	1.361259	Within groups	140.188800	108	1.298045		
Q5 Lecture	62	62	1.000000	1.311475	Between groups	93.011740	1	93.01174	63.58603	1.72E-12
Q5 POGIL	48	137	2.854167	1.659131	Within groups	157.979200	108	1.462770		
Q6a Lecture	62	37	0.596774	0.506875	Between groups	13.859050	1	13.859050	26.15288	1.38E-06
Q6a POGIL	48	63	1.312500	0.559840	Within groups	57.231850	108	0.529925		
Q6b Lecture	62	24	0.387097	0.339503	Between groups	29.850550	1	29.850550	59.12932	7.29E-12
Q6b POGIL	48	69	1.437500	0.719415	Within groups	54.522180	108	0.504835		
Q6c Lecture	62	31	0.500000	0.483607	Between groups	10.568180	1	10.568180	15.68885	0.000134
Q6c POGIL	48	54	1.125000	0.920213	Within groups	72.750000	108	0.673611		

perpetual use of the lecture method have been recorded as large class sizes and wide syllabi (Govender, 2015). Failure of DoBE (2020) to address the concerns of the teachers and lecturers impedes the transformation of teaching approaches from traditional to active. When teachers fail to pay attention to the active engagement of learners, they will assume that the learner's engagement during the lecture method whilst they may be disengaged or passively attending class. This lecture method encourages rote learning and does not lead to the understanding of concepts. The lecture method may allow the teacher to properly organize the topics and develop concepts in a logical manner but is ineffective when application of facts or critical thinking are required such as in science (Miller et al., 2013).

Analysis of the teachers' and learners' activities in POGIL group in the current study suggests the promotion of active engagement of learners. This agrees with the findings from (Strachan & Liyanage, 2015). Active learning has a positive effect on the cognitive development of learners as they invent concepts and develop understanding (Simonson, 2019).

The learners in the lecture classes spent most of the duration of the lessons in the 'Passive mode' while those in POGIL classes spent most time in the 'Interactive mode'. This agrees with the findings from (Miller et al., 2013). The reader should take note that the learners in POGIL group were in the 'passive' mode of engagement during the times when they listened to the 'reader' and to the teachers' instructions. The learners in POGIL classes were occupied with the class activities in their groups for the greater part of their lessons. These activities may have been the reason for the higher problem-solving competencies. This agrees with the findings in previous studies by Moog and Spencer (2008) and Simonson and Shadle (2013). On the other hand, the learners in the lecture group were in the 'passive' mode when they listened to the teacher. These learners did not have moments to listen to each other but only to the teacher. This agrees with the study by Govender (2015).

The current research witnessed an increase in the problem-solving skills of learners in stoichiometry after receiving lessons using both POGIL method and the lecture method. This explains some degree of effectiveness of lecture method. POGIL group showed statistically significantly higher problem-solving competencies than lecture group. This corroborates the previous findings by Omoniyi and Torru (2019).

The learners in POGIL group solved both simple and complex questions, while the learners in the lecture group had difficulties in solving both multi-step calculations and simple questions alike. As a result, the learners in POGIL group improved motivation as they actively and happily discussed the worksheets and improved achievement as indicated by the higher test scores. This agrees with the findings by Santoso et al. (2023).

Both the lecture and POGIL classes had an equal duration of four hours during which the same number of concepts were covered. This indicates that POGIL is not time-consuming in terms of lesson delivery. This finding disagrees with the findings by Mamombe et al. (2021), that POGIL is time consuming. In the current study we argue therefore, that POGIL is timeous during preparation of the worksheets and not during delivery of the lessons (Douglas, 2011).

The learners in POGIL classes were noisy. This agrees with the findings by Simonson (2019). The noise of POGIL classes were, however, constructive since the learners were engaged in the 'interactive' mode solving the worksheets. The learners in POGIL classes learned much more than those in the lecture class. The quietness of the learners in the lecture classes did not translate into problem-solving competencies. These learners lacked the skills to solve stoichiometry even though they seem attentive during the lecture lessons. This agrees with the findings by Miller et al. (2013).

CONCLUSIONS & RECOMMENDATIONS

The results of pre- and post-test indicate that the use of POGIL to teach stoichiometry produces statistically significantly higher problem-solving competencies as compared to using the lecture method. POGIL method also produces higher test scores as indicated by the higher sum and the averages of their test scores as compared to learners in the lecture group. The learners in POGIL classes were actively engaged most of the time and solved both the low-order and the high-order stoichiometry questions during the lessons and in the tests. This may have resulted in better problem-solving competencies in POGIL group compared to the lecture group. We conclude that POGIL rather than the lecture method is more effective in teaching stoichiometry, which is a complex abstract topic. The use of learner-centered teaching methods such as POGIL may be effective in increasing problem-solving competencies in learners. The use of POGIL in teaching stoichiometry is recommended since this approach elucidates and clarifies abstract and complex concepts.

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REFERENCES

Bantwini, B. (2017). Analysis of teaching and learning of natural and technology in selected Eastern Cape Province primary schools, South Africa. *Journal of Education, 67*, 40-63.

Bodner, G. M., & Herron, J. D. (2002). Problem-solving in chemistry. In J. K. Gilbert (Ed.), *Chemical education: Research-based practice* (pp. 235-266). Kluwer Academic Publishers. https://doi.org/10.1007/0-306-47977-X_11

Booi, K. (2023). Physical science educators' teaching approaches for facilitating conceptual understanding of stoichiometry. In *Proceedings of the 15th International Conference on Education and New Learning Technologies* (pp. 902-905). https://doi.org/10.21125/edulearn.2023.0332

Celikkiran, A. T. (2020). Examination of secondary school students' ability to transform among chemistry representations levels related to stoichiometry. *International Journal of Progressive Education, 16*(2), 42-55. https://doi.org/10.29329/ijpe.2020.241.4

Chi, M. T., Adams, J., Bogusch, E. B., Bruchok, C., Kang, S., Lancaster, M., Levy, R., Li, N., McEldoon, K. L., Stump, G. S., Wylie, R., Xu, D., & Yaghmourian, D. L. (2018). Translating ICAP theory of cognitive engagement into practice. *Cognitive Science, 42*(6), 1777-1832. https://doi.org/10.1111/cogs.12626

Creswell, J. W., & Clark, V. L. (2018). *Designing and conducting mixed methods research*. SAGE.

Dahsah, C., & Coll, R. K. (2007). Thai grade 10 and 11 students' conceptual understanding and ability to solve stoichiometry problems. *Research in Science and Technological Education, 25*(2), 227-241. https://doi.org/10.1080/02635140701250808

Davidowitz, B., Chittleborough, G., & Murray, E. (2010). Student-generated sub micro diagrams: A useful tool for teaching and learning chemical equations and stoichiometry. *Chemical Education Research and Practice, 11*, 154-164. https://doi.org/10.1039/C005464J

DoBE. (2012). Grades 10-12 physical sciences, national curriculum statement. *Government Printing Works*. www.info.gov.za

DoBE. (2019). National senior certificate diagnostic report. *Government Printing Works*. www.info.gov.za

DoBE. (2020). National senior certificate examination: School subject report. *Government Printing Works*. www.info.gov.za

Douglas, E. P. (2011). Student construction of knowledge in an active learning classroom. In *Proceedings of the ASEE Annual Conference & Exposition* (pp. 1-22). https://doi.org/10.18260/1-2--18479

Dudu, W. T. (2014). The changing roles of South African natural sciences teachers in an era of introducing a "refined and repackaged" curriculum. *Journal of Science Education, 7*(3), 547-558. https://doi.org/10.1080/09751122.2014.11890216

Govender, S. (2015). Students' perceptions of teaching methods used at South African higher education institutions. *South African Journal of Higher Education, 29*(3), 23-41. https://doi.org/10.20853/29-3-486

Hu, H. H., Kussmaul, C., Knaeble, B., Mayfield, C., & Yadav, A. (2016). Results from a survey of faculty adoption of process oriented guided inquiry learning (POGIL) in computer science. In *Proceedings of the Conference on Innovation and Technology in Computer Science Education* (pp. 186-191). ACM. https://doi.org/10.1145/2899415.2899471

John, M. (2019). Physical sciences teaching and learning in Eastern Cape rural schools: Reflections of pre-service teachers. *South African Journal of Education, 39*, 1-12. https://doi.org/10.15700/saje.v39ns1a1660

Kibirige, I., & Mamashela, D. (2022). Learners' prevalent misconceptions about force and experiences of flipped classes. *Journal of the Education of Gifted Young Scientists, 10*(1), 109. https://doi.org/10.17478/jegys.1058677

Kibirige, I., Osodo, J., & Tlala, K. M. (2014). The effect of predict-observe-explain strategy on learners' misconceptions about dissolved salts. *Mediterranean Journal of Social Sciences, 5*(4), 300-300. https://doi.org/10.5901/mjss.2014.v5n4p300

Lawson, A. E. (1988). A better way to teach biology. *The American Biology Teacher, 50*(5), 266-278. https://doi.org/10.2307/4448733

Lotlikar, P. C., & Wagh, R. (2016). Using POGIL to teach and learn design patterns–A constructionist based incremental, collaborative approach. In *Proceedings of the 2016 IEEE 8th International Conference on Technology for Education* (pp. 46-49). IEEE. https://doi.org/10.1109/T4E.2016.018

Makhechane, M., & Qhobela, M. (2019). Understanding how chemistry teachers transform stoichiometry concepts at secondary level in Lesotho. *South African Journal of Chemistry, 72*, 59-66. https://doi.org/10.17159/0379-4350/2019/v72a9

Malcolm, S. A., Mavhunga, E., & Rollnick, M. (2019). The validity and reliability of an instrument to measure physical science teachers' topic specific pedagogical content knowledge in stoichiometry. *African Journal of Research in Mathematics, Science and Technology Education, 23*(2), 181-194. https://doi.org/10.1080/18117295.2019.1633080

Mamombe, C., Mathabathe, K. C., & Gaigher, E. (2021). Teachers' and learners' perceptions of stoichiometry using POGIL: A cases study in South Africa. *EURASIA Journal of Mathematics, Science and Technology Education, 17*(9), em2003. https://doi.org/10.29333/ejmste/11140

Mandina, S., & Ochonogor, C. E. (2018). Recurrent difficulties: Stoichiometry problem-solving. *African Journal of Educational Studies in Mathematics and Science, 14*, 25-31. https://doi.org/10.29333/ejmste/95125

Marais, F., & Combrinck, S. (2009). An approach to dealing with difficulties undergraduate chemistry students experience with stoichiometry. *South African Journal of Chemistry, 62*, 88-96.

McGuire, Z. S. Y., & McGuire, S. (2015). *Teach students how to learn*. Stylus Publication.

Miheso, J. M., & Mavhunga, E. (2020). The retention of topic specific PCK: A longitudinal study with beginning chemistry teachers. *Chemistry Education Research and Practice, 21*, 789-805. https://doi.org/10.1039/D0RP00008F

Miller, C. J., McNear, J., & Metz, M. J. (2013). A comparison of traditional and engaging lecture methods in a large, professional-level course. *Advances in Physiology Education, 37*(4), 347-355. https://doi.org/10.1152/advan.00050.2013

Mohafa, L. G., Qhobela, M., & George, M. J. (2022). Evaluating the influence of interactive simulations on learners' academic performance in stoichiometry. *South African Journal of Chemistry, 76*, 1–8. https://doi.org/10.17159/0379-4350/2022/v76a01

Moog, R., & Spencer, J. (2008). POGIL: Process oriented guided inquiry learning. In *Proceedings of the ACS Symposium*. American Chemical Society. https://doi.org/10.1021/bk-2008-0994

Omoniyi, A. O., & Torru, T. E. (2019). Effectiveness of process oriented guided inquiry teaching strategy on students' performance in chemistry in secondary schools in Ondo State Nigeria. *American International Journal of Education and Linguistics Research,* 2(1), 34-38. https://doi.org/10.46545/aijelr.v2i1.73

Owoyemi, T. E., & Amahwe, S. E. (2020). Mathematical problem-solving skill and conceptual understanding as correlates of senior secondary school students' achievement in stoichiometric aspect of chemistry. *Nigerian Online Journal of Educational Sciences and Technology,* 2(1), 71-79.

Saadah, N., Haryani, S., & Mahatmanti, W. (2022). Analysis of chemical misconceptions of stoichiometry materials using certainty of response index. *International Journal of Active Learning, 7*(1), 94-102.

Santoso, A., Sumari, S., & Setiadi, A. D. (2023). The effect of POGIL classroom on students' achievement and motivation on acid-based topics. *AIP Conference Proceedings, 2569*, 030006. https://doi.org/10.1063/5.0112292

Simonson, S. R. (2019). *An introduction to process oriented guided inquiry learning for those who want to empower learners*. Stylus Publishing.

Simonson, S. R., & Shadle, S. E. (2013). Implementing process oriented guided inquiry learning (POGIL) in undergraduate biomechanics: Lessons learned by a novice. *Journal of STEM Education, 14*(1), 56-63.

Stott, A. E. (2020). Influence of context on stoichiometry conceptual and algorithmic subject matter knowledge among South African physical sciences teachers. *Journal of Chemical Education, 97*(5), 1239-1246. https://doi.org/10.1021/acs.jchemed.9b01056

Stott, A. E. (2021). South African physical sciences teachers' use of formulae and proportion when answering reaction-based stoichiometry calculation questions. *Chemistry Education Research and Practice, 22*(2), 443-456. https://doi.org/10.1039/D0RP00291G

Strachan, R., & Liyanage, L. (2015). Active student engagement: The heart of effective learning. In P. L. Layne (Ed.), *Global innovation of teaching and learning in higher education*. Springer. https://doi.org/10.1007/978-3-319-10482-9_16

Sunday, E. I., Ibemenji, K. A. G., & Alamina, J. I. (2019). Effect of problem-solving teaching technique on students' stoichiometry academic performance in senior secondary school chemistry in Nigeria. *Asian Journal of Advanced Research and Reports, 4*(3), 1-11. https://doi.org/10.9734/ajarr/2019/v4i330110

APPENDIX A: PRE-TEST

Stoichiometry Grade 11

Time: One hour

Answer ALL the following questions showing ALL the calculations as clearly as possible. DO NOT write only the answers. Write all final answers to two decimal places.

Table A1. Pre-test

1.	There are 0.2 moles of pure Na in a crucible. Calculate the mass of the Na in the crucible.	(3)
2.	How many O atoms are present in 245g sample of CO_2?	(5)
3.	$CuO(s)+H_2(g)\rightarrow Cu(s)+H_2O(g)$	(5)
3(a)	Consider the balanced reaction above.	
	If 25 g of CuO reacts completely in the reaction, calculate the mass of Cu produced in the reaction.	
3(b)	Calculate the volume of H_2 gas used.	(5)
4.	Given the balanced chemical reaction: $2NO(g)+O_2(g)\rightarrow 2NO_2(g)$	(2)
	Define the term limiting reagent.	
4(b)	Calculate mass of nitrogen dioxide that can be made when 20 g of NO react with 20 g of O_2 in gaseous phase.	(8)
5.	Which of the following solutions has the highest concentration of chloride ions?	(8)
	10 g of NaCl dissolved in 50 cm^3 of solution.	
	15 g of $CaCl_2$ dissolved in 100 cm^3 of solution.	
	20 g of $CrCl_3$ dissolved in 125 cm^3 of solution.	
6.	15 cm^3 of 0.4 $moldm^{-3}$ solution of H_2SO_4 reacted with 20 cm^3 of NaOH of concentration 0.5 $moldm^{-3}$.	(2)
6(a)	Write a balanced equation of this reaction.	
6(b)	Calculate the number of moles of H_2SO_4.	(3)
6(c)	Calculate the number of moles of NaOH.	(3)

APPENDIX B: POST-TEST

Stoichiometry Grade 11

Time: One hour

Answer ALL the following questions showing ALL the calculations as clearly as possible. DO NOT write only the answers. Write all final answers to two decimal places.

Table B1. Post-test

1.	There are 0.5 moles of pure Mg in a crucible. Calculate the mass of the Mg in the crucible.	(3)
2.	How many moles of O atoms are present in 25 g sample of N_2O_4?	(7)
3.	$CaO(s)+CO_2(g)\rightarrow CaCO_3(s)$	(5)
3(a)	Consider the balanced reaction above. If 25 g of CaO reacts completely in the reaction, calculate the volume of CO_2 used.	
3(b)	Calculate the mass of $CaCO_3$ produced.	(5)
4(a)	Given the balanced chemical reaction: $2H_2(g)+O_2(g)\rightarrow 2H_2O(g)$ Define the term limiting reagent.	(2)
4(b)	Calculate the mass of water that can be made from 20 g of H_2 and 40 g of O_2 in the gaseous phase.	(8)
5.	Which of the following solutions has the highest concentration of HYDROGEN IONS? 10 g of H_2SO_4 dissolved in 250 cm^3 of solution. 15 g of HCl dissolved in 100 cm^3 of solution.	(8)
6	There are 20 cm^3 of HCl with concentration 0.3 $moldm^{-3}$ which react with 23 cm^3 of NaOH of concentration 0.25 $moldm^{-3}$. $HCl(aq)+NaOH(aq)\rightarrow NaCl(aq)+H_2O(l)$ a) Calculate the number of moles of NaOH. b) Calculate the number of moles of HCl. c) Which substance between NaOH and HCl is limiting reactant?	(2) (3) (3)