From the familiar to the abstract: Exploring grade 11 learners' development in stoichiometry problem solving competency with exposure to POGIL

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Abstract

This qualitative case study explored how exposure to Process-Oriented Guided Inquiry Learning (POGIL) improves 11^{th}-grade physical sciences learners' competency in solving stoichiometry problems. Two township schools of low socioeconomic status in Pretoria, South Africa, were conveniently and purposively sampled. Two classes (N=48) composed of multi-cultural black learners of mixed gender participated in the study. Data were collected at each school using a pre-test, a post-test, and observation with video recording during the POGIL intervention. The Interactive-Constructive-Active-Passive (ICAP) theory served as a conceptual and analytic framework to understand the nature of student engagement during the POGIL activities. High student engagement could contribute to improved problem-solving competency in the post-test. The findings from the classroom observations and video-recorded group discussions serve as evidence of the learners' engagement. The majority of their interactions were characterized as interactive and constructive modes of engagement, both facilitating deep processing strategies. Regarding data from the tests, problem-solving competency levels were classified at four competency levels based on Bloom's taxonomy. The pre-test indicated that the learners lacked competency in solving complex stoichiometry problems. Analysis of their responses revealed higher-order thinking skills in the post-test. ANOVA indicated that the differences in the frequencies of the competency levels found in the pre-test and post-test are statistically significant. The learners collaboratively engaged in the analysis, synthesis, and evaluation of ideas, reasoning, and justifying their suggestions in solving POGIL activities. The study shows how using POGIL in high school science may empower learners with enhanced problem-solving skills.

Keywords

Process Oriented Guided Inquiry Learning (POGIL), stoichiometry, active learning, problem solving

Introduction

Stoichiometry is a challenging major chemistry topic that involves the mole concept, quantities of products and reactants, and limiting reactants (Department of Basic Education [DoBE] Report, 2019). Learners' lack of understanding, misconceptions, and difficulty in solving stoichiometry calculations have been reported internationally (Kimberlin & Yezierski, 2016). In South Africa (SA), high school learners (Malcolm, et al., 2019) and first-year university students (Marais & Combrinck, 2009) have difficulties balancing equations of reactions and identifying the limiting reactant in stoichiometry. University students' challenges in stoichiometry and their tendency to use memorization may be a result of prolonged use of lecture methods at the school level regardless of the expectations of the current, inquiry-aligned Curriculum, Assessment and Policy Statement (CAPS) (Ramnarain & Schuster, 2014). Furthermore, some SA high school teachers lack sufficient knowledge in calculations involving proportion (ratio) in stoichiometry (Stott, 2021). This

knowledge deficiency of SA teachers, pre-service teachers, and learners in stoichiometry may be as a result of ineffective teaching methods, among other causes. However, a careful choice and use of a different teaching approach may be a solution to low achievement in stoichiometry (Mandina & Ochonogor, 2018; Stott, 2021).
The use of learner-centred collaborative active inquiry methods such as Process Oriented Guided Inquiry Learning (POGIL) may be a solution to SA learners' challenges in stoichiometry. During POGIL classes, learners work in groups of four to six, completing specially designed worksheets that guide them from the simple to the more complex concepts (Moog & Spencer, 2008; Simonson, 2019). The current study aims to explore how POGIL fosters SA learners' competency in solving stoichiometry problems. While most of the studies on the use of POGIL in science classrooms across the globe utilized the quantitative methodology to demonstrate the impact of POGIL on academic performance, the current study takes a qualitative approach to explore the effect POGIL has on students' problem solving abilities.

In the context of this study problem solving competency is defined as a learner's ability to successfully execute simple to complex stoichiometry problem solving strategies to solve routine exercises to novel problems (Bodner & Herron, 2002). We explored the nature of stoichiometry problem solving competency demonstrated by grade 11 learners before and after exposure to POGIL activities.

The main research question for this study was;

How do learners' stoichiometry problem solving skills develop during POGIL activities?

The sub-research questions were;

1. What is the nature of the learners' initial problem solving competency in stoichiometry?
2. What is the nature of the learners' cognitive engagement during the POGIL intervention?
3. What is the nature of the learners' problem solving competency in stoichiometry after the intervention?

Literature review

Low achievement in SA high school physical sciences have been observed in the calculation of moles, applying the mole ratio, and identifying limiting reactants, which are essential aspects of stoichiometry (Department of Basic Education [DoBE] subject report, 2020; Malcolm, et al., 2019). Some learners showed lack of mental constructs in balancing chemical equations of reactions (Barke, et al., 2009). Learners in Thailand demonstrated similar challenges of confusing reacting mass and molar mass; using mass ratio instead of mole ratio; identifying a limiting reagent as the reactant with the least number of moles, among others (Dahsah & Coll, 2007). However, exposure to problem-solving activities as opposed to conventional lecture method reduced Zimbabwean learners' misconceptions in balancing chemical equations of reactions, identifying the limiting reactant, among others (Mandina & Ochonogor, 2018). Similar results were obtained among Thai learners' (Chonkaew, et al., 2016). Challenges in stoichiometry can be mitigated by, among other ways, using a teaching approach that provides procedures to assist learners' understanding of the concepts (Mandina & Ochonogor, 2018; Tharayil, et al., 2018).

POGIL has been observed to improve understanding and achievement of abstract topics such as stoichiometry (Simonson, 2019), while it also supports learning in both privileged and disadvantaged contexts (Kurumeh, et al., 2012; Simonson, 2019). POGIL worksheets are designed to stimulate active learning, thinking and conceptual understanding rather than memorizing (Ozgelen, et al., 2012); and focus on investigative approaches to generate knowledge rather than rote learning (Furtak, et al., 2012). Use of POGIL improved Saudi learners' active engagement and supported understanding (Alghamdi & Alanazi, 2020); encouraged better communication, teamwork and better learning outcomes of American learners (Hu, et al., 2016), and developed inquiry skills (Renee, et al., 2019).

Statistically significant differences in critical thinking skills and problem-solving skills were observed in favour of the POGIL group compared to the lecture group of university chemistry students (Irwanto, et al., 2018; Muhammad & Purwanto, 2020). In mathematics, learners taught using POGIL improved logical thinking ability in solving problems (Andriani, et al., 2019). High school learners taught using POGIL had an improved pass rate compared to those using the conventional lecture method (Walker & Warfa, 2017). During POGIL activities, teachers act as facilitators, asking probing questions that assist learners to think critically and justify their responses (Daubenmire, et al., 2015) which develops high-level cognitive and metacognitive skills (McGuire & McGuire, 2015).

Conceptual framework

The Interactive-Constructive-Active-Passive (ICAP) framework (Chi, et al., 2018), a constructivist theory that acknowledges the development of mental constructs (Vygotsky, 1934/1986) is a useful analytic framework for characterising learner modes of cognitive engagement. The framework, shown in Figure 1, identifies learners' cognitive engagement during a task that can be associated with some observable actions. The learners' "on-task" actions are cognitive engagements in either of the interactive, constructive, active, or passive modes. The learners' "off-task" actions are cognitive disengagements where learners may be daydreaming, absentminded, asleep, or unfocused. The interactive and constructive engagements represent minds-on, in-depth processing of information and an indication that high order thinking skills are at work. The active and passive engagements suggest low-order shallow processing strategies. Active learning is associated with the 'interactive', 'constructive' and the 'active' cognitive engagements (Chi, et al., 2018).

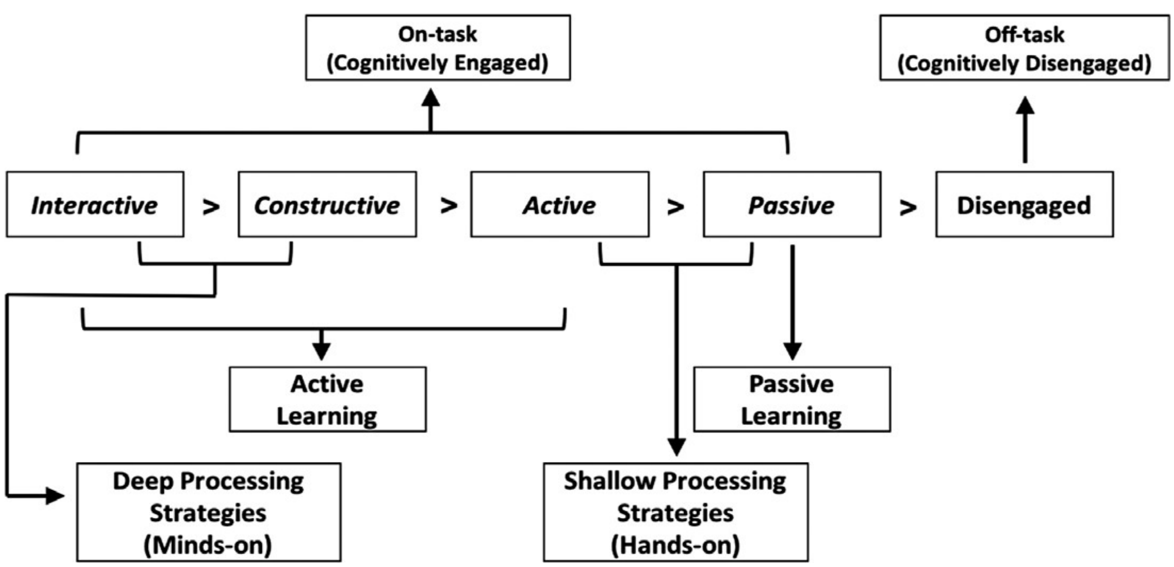


Figure 1. The ICAP theory of cognitive engagement (Chi, et al., 2018)

The interactive mode occurs when learners are actively engaged in discussions and sharing their views supported with justification, elaborating, justifying, explaining, challenging, and adding on previous speakers' ideas or questioning each other's ideas until they agree on a common answer. During the constructive mode learners construct their ideas individually by applying reasoning but not sharing with others. Constructive engagement behaviours include explaining, taking notes in one's own words, posing problems, asking questions, drawing a concept map, predicting, inventing, arguing, inducing hypotheses, self-evaluating or monitoring one's understanding. Typical active engagements include pointing to or gesturing, repeating, copying, rehearsing, underlining, or choosing. During the passive mode, the learners are paying attention and receiving information such as reading silently, watching a video, or listening to instructions.

Using the ICAP framework, the current study assumed that the learners' cognitive engagement can be identified by their evident behaviours during group discussions while completing POGIL worksheets and that deep –processing strategies may facilitate the development of problem-solving competencies.

Methodology

A case study methodology was deemed suitable because it provides rich and detailed qualitative data and insights on the situation. The data constitute learners' answers in the pre- and the post-tests, and video recordings of the learners' group activities during the intervention. Different methods of data collection are utilised and the use of an expert to validate the coding of the data, followed by discussions to reach consensus, enhanced trustworthiness.

Sampling

Before commencing data collection, 25 high school science teachers from a district in Pretoria were trained to teach using POGIL during a three-day professional development workshop undertaken by a university to promote the use of POGIL in schools. The schools were all English-medium, multi-cultural township schools of low socioeconomic status. After the training, all the teachers were invited to participate in the study. Two of the teachers indicated their willingness to participate. These two teachers were requested to practice POGIL at their respective schools, and have data collected during a POGIL session focusing on teaching stoichiometry to one of their Grade 11 classes. At school A, 22 learners out of 36 consented to participate in the study and were placed in 5 groups. At school B, 26 out of 42 learners consented to participate in the study and formed 6 groups.

Description of the Test instrument

The questions in the pre- and the post-test were matched to ensure similar questions in the two tests. The questions varied in terms of the different levels of complexity and cognitive demand based on Bloom's taxonomy of cognitive domains as shown in Table 1. According to the standards used by the DoBE (2020), levels I and II correspond to cognitive levels 1 and 2 of Bloom's taxonomy. Level III is a combination of cognitive levels 3 and 4, while level IV is a combination of cognitive levels 5 and 6. (Anderson & Krathwohl, 2001; McGuire & McGuire, 2015). Both tests were designed and carefully structured by the primary researcher adapting the questions from previous examinations on stoichiometry. The test questions addressed various skills assessed in the examination and scaffolded around Bloom's taxonomy of cognitive domains. Most of the questions required mathematical knowledge and skills such as ratios, calculations, changing the subject of formula and simple substitution in the correct formula. The tests were validated by an expert in chemistry education. Trustworthiness of the tests was acertained by the second author and the two participating teachers. They checked the language, and clarity of questions to alleviate any ambiquity.

Table 1. Question items and associated problem solving skills required in the pre- and post-tests

Pre and post-test Question & DoBE level	Problem solving skill required	Bloom's Cognitive levels	Stoichiometry problem solving skills assessed
1 – I	Recall	Understanding	Identify correct formula. Substitute in the formula, identify the correct atomic mass.
2 – III	Ratio	Analyse, apply, evaluate	Choose the correct formula, substitute appropriately. Link two formulae using mole ratio.
3a – III	Ratio	Analyse, apply, evaluate	Choose the correct formula, substitute appropriately. Link two formulae using mole ratio.
3b – II	Ratio	Analyse, apply, evaluate	Use balanced equation of reaction and mole ratio, substitute appropriately, and calculate the final answer.
4a – I	Recall	Remember	Remember the definition of limiting reactant.
4b – IV	Ratio	Analyse, apply, create, evaluate	Choose the correct formula, substitute appropriately. Use mole ratio from balanced chemical reaction to link formulae.
5 – IV	Ratio, comparison	Analyse, apply, create, evaluate	Calculate molecular mass of the 3 compounds, convert cm^3 to dm^3, choose the correct formula, and substitute appropriately. Use mole ratio calculation and compare number of moles.
6a – II	Ratio, comparison	Analyse, apply, evaluate	Count number of atoms of each element. Compare on both sides of equation. Balance using suitable coefficient.
6b – II	Ratio	Analyse, apply, evaluate	Use appropriate ratio, choose the correct formula, substitute appropriately, and calculate the answer.
6c – II	Ratio	Analyse, apply, evaluate	Use appropriate ratio, choose the correct formula, substitute appropriately, and calculate the answer.

The stoichiometry POGIL intervention

Existing POGIL worksheets (from www.pogil.org) were adapted to the South African context and used to guide the inquiry component of the group activities. The main change effected was the spellings of words such as "tires" to "tyres" which is widely used in South Africa. One of the questions was phrased as "*Which part limits the number of cars that you can make?*" This question was adapted to "*Which part (engines, tyres, bodies or cylinders) limits (stops you from making) the number of cars that you can make?*". This form of adaptation was made to ensure that language would not be a barrier to learners satisfactorily answering the questions.

The design of each POGIL worksheet is such that each activity follows the learning cycle, consisting of the exploration, invention, and concept application phases (Lawson, 1988), starting from simple to complex concepts, as learners develop their own understanding of concepts and problem solving skills in a scaffolded manner. The first activities, called *Models*, in the intervention were presented as introductory, to stimulate prior knowledge and remind learners of familiar foundational concepts which relate to the science concepts under study. Subsequently, the learners focused on the core science topics, starting with the simple to the more complex concepts.

Data collection and analysis

All data were collected at the learners' respective schools on successive weekends. The pre-test was administered, followed by a POGIL intervention taught by their usual science teacher and observed by the researcher. Each group discussion was video recorded by the learners capturing only their voices, and what they wrote down, but not their faces. The learners' responses to the stoichiometry questions in the pre-test could be informed by the prior knowledge acquired through the conventional teaching in previous grades, while that in the post-test could be in part attributed to their exposure to the POGIL activities.

The non-participant classroom observation by the researcher was essential for observing the learners' off-camera activities and observe the roles played by the teachers during the intervention.

The ICAP framework was used to characterise the learners' coginitve engagement as they transitioned from one mode to another. All groups had a 'reader' responsible for reading out the question to the group. The group would be attentive to the reader without writing anything down. This was characterised as the passive mode. Next, learners would start brainstorming to find possible solution to the question without talking to anyone. This was the constructive mode. One learner at a time under the leadership of the 'manager' would share their idea with the group. The other members would respond one after another in affimation, contradiction, or adding onto the former idea. This is the interactive mode.

After the intervention, a post-test was administered. The researchers could infer the gain in problem solving competency from the learners' answers to the pre- and post-test questions. The analysis of the learners' test scripts enabled the researchers to establish the learners' competency in solving stoichiometry problems which entailed identifying unknown and known variables (quantities), selecting appropriate formulae, applying suitable ratios, converting units, correctly substituting values, altering the subject of the formula and calculating the answer and using appropriate ratios in multi-step calculations. Responses in the pre- and post-test led to the development of a rubric that charaterised the learners' problem solving competency levels as Novice, Elementary, Intermediate, Competent and Advanced (Table 2). The coding done initially by the primary researcher was checked by the second author and discrepancies were discussed to reach agreement.

Table 2 provides a summary of possible problem solving competency levels depending on the level of complexity of each question. Responses were classified as Novice to a question of any level when a learner could not at the least show a formula, provide any response, or presented a formula without substitution, or something was wrong with the definition. The Elementary competency was characterised by a response to a question of any complexity level which entailed provision of a correct definition or single-step calculation that involved the identification of the correct formula followed by the appropriate substitution and provision of a correct answer. A response was classified as Intermediate to a more cognitively demanding question (cognitive domain level II, III, or IV) when the answer involved two step-calculations. An answer was identified as Competent on a level III or level IV question, when three-step calculations were correctly followed. A response was classified as Advanced to a level IV question when four-step calculations were correctly completed. Table 2 shows that for questions of complexity level I, responses could be coded as Novice or Elementary, questions of complexity level II coded as either Novice, Elementary or Intermediate, questions of complexity levels III could be coded as Novice, Elementary, Intermediate, Compentent, while responses to complexity level IV questions could becoded as Novice, Elementary, Intermediate, Competent or Advanced.

Table 2. Classification of learner responses in terms of problem solving competency per question in the test

Level of complexity and cognitive demand	Item number(s) in the pre- and post-test	Number of correct steps in response	Classification of Problem solving competency
I	1	0	Novice
	4a	1	Elementary
	3b	0	Novice
II	6a,6b,	1	Elementary
	6c	2	Intermediate
	2	0	Novice
III		1	Elementary
	3a	2	Intermediate
		3	Competent
	4b	0	Novice
		1	Elementary
IV	5	2	Intermediate
		3	Competent
		4	Advanced

The use of ATLAS.ti helped to organise and summarise all data from different sources, i.e. types of cognitive engagement during the completion of the POGIL activities as well as the types of problem solving competency levels in the pre- and post-test responses. The coding instrument which aimed at coding and quantifying the frequency of occurrence of codes was used by both the first and the second coder. Consensus was reached by the two coders that the work was fairly coded. The use of Table 2 together with the marking guidelines, during the coding process ensured dependabability of the coding provided by both coders.

Results

Problem solving competency as inferred from the Pre- and Post-test responses

An example of Competent problem solving is shown in Figure 2. In the pre-test question 3a required a three-step calculation. A learner used the correct formula and calculated the number of moles of CaO, appropriately (step 1), then used ratios to calculate the equivalent number of moles of CO_2 (step 2). Thereafter, the learner used the appropriate formula to calculate the volume of CO_2 (step 3). Since three steps were correctly used to respond to this question, the problem solving approach was classified as Competent.

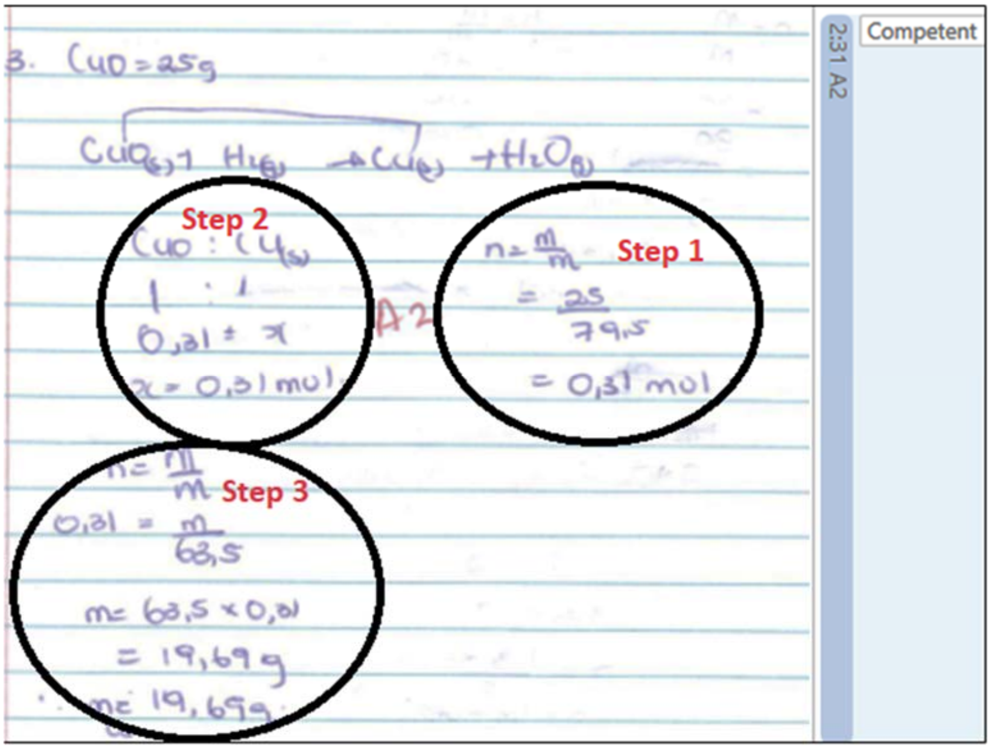


Figure 2. An example of a response showing "Competent problem solving" to question 3a

Table 3 shows the number of answers at different competency levels for each question, in the pre- and post-test. In the pre-test no learner in the sample demonstrated Advanced levels of solving stoichiometry problems compared to 24 in the post-test. In the pre-test most learners demonstrated Novice and Elementary levels of problem solving.The learners failed to solve questions requiring both lower-order and higher-order thinking skills. The problem solving competency did not match the cognitive demand of the question in terms of sophistication and the number of mathematical and procedural steps required.

Table 3. Pre- and post-test results (n = 48 learners)

Question	Advanced		Competent		Intermediate		Elementary		Novice	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
1	0	0	0	0	0	0	35	47	13	1
2	0	0	2	35	2	6	7	5	37	2
3(a)	0	0	3	36	2	8	9	4	34	0
3(b)	0	0	0	0	3	27	9	15	36	6
4(a)	0	0	0	0	0	0	12	42	36	6
4(b)	0	6	1	28	3	11	7	0	37	3
5	0	18	4	18	6	4	9	3	29	5
6(a)	0	0	0	0	6	23	7	17	35	8
6(b)	0	0	0	0	0	32	15	5	33	11
6(c)	0	0	0	0	0	25	13	4	35	19
Totals	**0**	**24**	**10**	**117**	**22**	**136**	**123**	**142**	**325**	**61**
Percentage	**0.0%**	**2.5%**	**1.0%**	**12.2%**	**2.3%**	**14.2%**	**12.8%**	**14.8%**	**33.9%**	**6.4%**

The post-test results suggest an improvement in problem solving competency of questions requiring both low and higher-order thinking as demonstrated by the learners responses which could be characterised as Advanced, Competent, and Intermediate (Table 3). This suggests that the learners improved problem solving competency after the intervention by solving more complex questions such as those evaluating Bloom's cognitive domains II, III and IV. The trend shows a shift of responses towards more proficient levels of problem solving in the post-test as compared to the pre-test.

ANOVA (Holton & Burnett, 2005) was performed to determine whether the differences observed in the pre- and post-test were significant. ANOVA tests seemed suitable because there was only one independent variable (teaching method) and the dependent variable was learners' problem solving classification. The effect of the change in the teaching method was measured in the learners' responses to the pre- and the post-test. Comparisons were done per question as corresponding questions in the two tests had the same levels of complexities.

Table 4 shows the results of the ANOVA tests of corresponding pre- and post-test responses. The results indicate that all p-values are smaller than alpha (0.05), and that the sums of the post-test were higher than of the pre-test. This suggests that the learners' problem solving competency is significantly higher in the post-test compared to the pre-test.

Table 4. ANOVA for pre- compared to post-test results

Question	*Count*	*Sum*	*Average*	*Variance*	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*
Q1 Pre-test	48	35	0.729167	0.201684	Between Groups	1.5	1	1.5	13.48207	0.0004
Q1 Post-test	48	47	0.979167	0.020833	Within Groups	10.45833	94	0.111259		
Q2 Pre-test	48	17	0.354167	0.574025	Between Groups	114.8438	1	114.8438	177.2751	2.35E-23
Q2 Post-test	48	122	2.541667	0.721631	Within Groups	60.89583	94	0.647828		
Q3a Pre-test	48	22	0.458333	0.721631	Between Groups	117.0417	1	117.0417	209.2282	1.22E-25
Q3a Post-test	48	128	2.666667	0.397163	Within Groups	52.58333	94	0.559397		
Q3b Pre-test	48	15	0.3125	0.347074	Between Groups	30.375	1	30.375	71.15888	3.86E-13
Q3b Post-test	48	69	1.4375	0.506649	Within Groups	40.125	94	0.426862		
Q4a Pre-test	48	32	0.666667	0.22695	Between Groups	1.041667	1	1.041667	6.151832	0.014907
Q4a Post-test	48	42	0.875	0.111702	Within Groups	15.91667	94	0.169326		
Q4b Pre-test	48	16	0.333333	0.48227	Between Groups	110.5104	1	110.5104	119.8901	1.8E-18
Q4b Post-test	48	119	2.479167	1.361259	Within Groups	86.64583	94	0.921764		
Q5 Pre-test	48	33	0.6875	0.985372	Between Groups	112.6667	1	112.6667	85.20818	7.94E-15
Q5 Post-test	48	137	2.854167	1.659131	Within Groups	124.2917	94	1.322252		
Q6a Pre-test	48	19	0.395833	0.499557	Between Groups	20.16667	1	20.16667	38.07197	1.71E-08
Q6a Post-test	48	63	1.3125	0.55984	Within Groups	49.79167	94	0.529699		
Q6b Pre-test	48	15	0.3125	0.219415	Between Groups	30.375	1	30.375	64.70822	2.58E-12
Q6b Post-test	48	69	1.4375	0.719415	Within Groups	44.125	94	0.469415		
Q6c Pre-test	48	13	0.270833	0.201684	Between Groups	17.51042	1	17.51042	31.21573	2.24E-07
Q6c Post-test	48	54	1.125	0.920213	Within Groups	52.72917	94	0.560949		

Student engagement as inferred from students' discussions during the the POGIL intervention

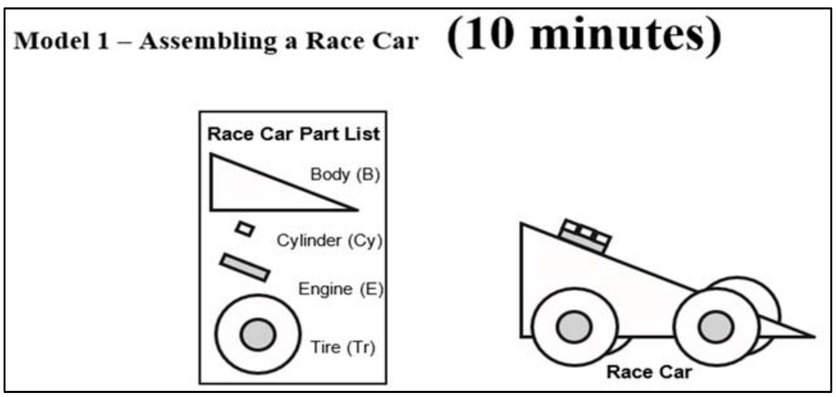
The nature of cogntive engagement demonstrated by the learners as they completed the POGIL activities was characterised by using the constructs stipulated in the ICAP framework (Figure 1).

In this section we provide illustrative examples of extracts from the transcripts of the learners' discussions during the POGIL tasks to indicate the nature of cognitive engangement.

The below question from an introductory POGIL activity was used for learners to work through a worksheet with an anology using familiar concepts like the number of tyres, engines, bodies and cylinders needed to construct a car to build conceptual understanding on the concept of limiting reactants, a key concept in stoichiometry. This is the typical design of POGIL worksheets, progressing from the simple, familiar concepts to the more complex subject matter concepts following multiple learning cycles to facilitate concept development.

Model 1 question 2 read as follows:

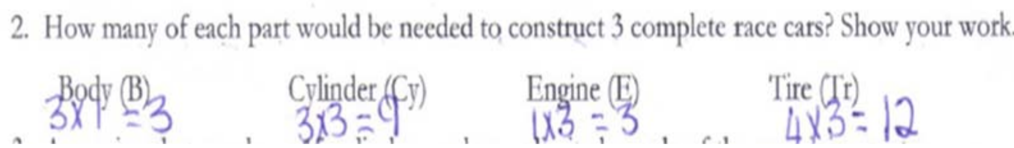
How many of each part would be needed to construct 3 complete race cars? Show your work.



One learner spoke up saying, "*To make three complete race cars, okay we are going to multiply each part by three, right?*" Another learner responded, "*yeah*". The group responded, saying, "*Bodies = 1x3 = 3 bodies; 3x3 = 9 cylinders; 1x3 = 3 engines and 4x3 = 12 tyres*". The learners quickly calculated and agreed on the answers before writing them down. The learners' level of cognitive engangement was characterised as **interactive** since they shared ideas and agreed on the collective response to the question. The level of engagement was interactive and collaborative because the learners provided their ideas one at a time, while others responded by questioning or supporting the other learner. They agreed on each answer with everyone of them involved in the discussion. The answers were a product of the group and not of one individual. Table 5 shows the groups' answers as well as the researchers' evaluation of their activities and level of engagement in this task.

Table 5. Learner activities and mode of engagement for POGIL question 2, Model 1

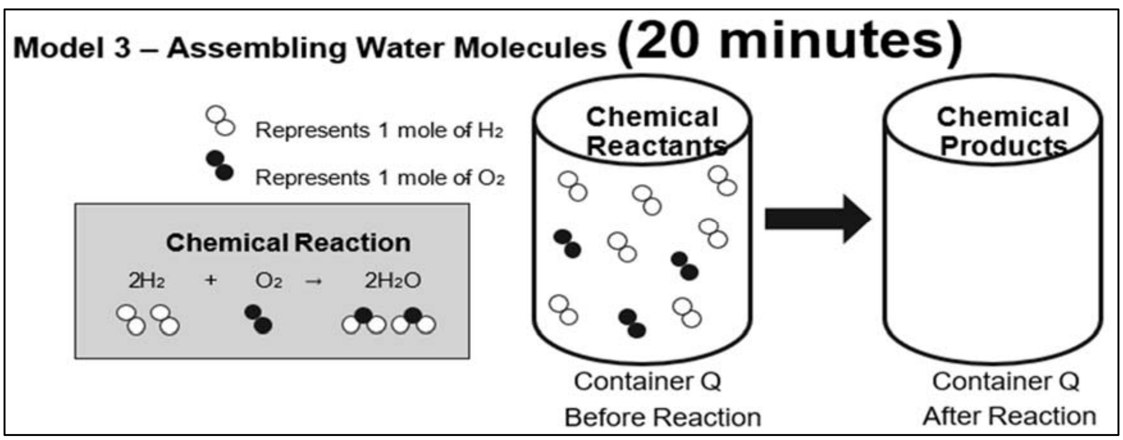
Activities	Mode of engagement
Agree, elaborate, compile ideas, justify	Interactive



The following example shows a more complex activity from the POGIL worksheet.

Model 3 question 12 read as follows:

Draw the maximum number of moles of water molecules that can be produced from the reactants shown and draw any remaining number of moles of reactants in the container after reaction.



The learners discussed the number of atoms and collectively agreed that each water molecule has 1 oxygen atom. *"So, each water molecule has 1 oxygen and 2 hydrogens, right?"*. One learner remarked, "*Yes, just like each car has 1 body and 4 tyres*". They circled pairs of 2 hydrogen atoms together with 1 oxygen atom in the jar with reactants, with one pair of hydrogen atoms remaining as shown in table 6. "*So we have 6 moles of water produced and one mole of hydrogen in excess"*, the learners concluded. The mode of engagement demonstrated by the learners in answering this question was classified as **interactive** based on the activities of the learners. The learners individually constructed their ideas, and brought them to the group where the other members either supported or questioned the correctness of the ideas. The final answer written down by the learners belonged to the group rather than individual learner because all learners contributed to the final answer. Table 6 shows the representation of the learners' response to this question.

Table 6. Learner activities and mode of engagement for POGIL question 12, Model 3

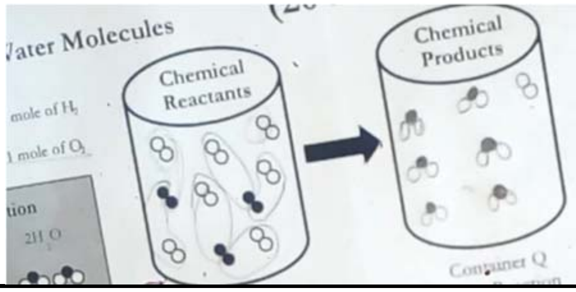
	Activities	Mode of engagement
	Justify, elaborate, argue, compile ideas, agree, highlight	Interactive
Image		

Table 7 shows a summary of the learners' behaviours as an indication of the nature of their cognitive engagement from the video analysis of some of the selected videos based on the ICAP framework. The learners' cognitive engagement was largely interactive, as they actively collaborated and assisted each other in solving problems. Learners' attention was evident in the passive mode where they listened carefully to the reader. Disengagement appeared with low frequency, indicating that the intervention kept the learners focused on the worksheet. The active mode appeared the least, probably because the activities did not involve a lot of argumentation.

Table 7. Learners' activities during the intervention based on the ICAP framework

Mode of cognitive engagement	**Codes of learner behaviour and frequency of occurrence**	**Totals**
Interactive	Agreement (33); argument (14); challenge (21); comparison (6); compile ideas (30); elaborate (29); justify (21)	154
Constructive	Brainstorming (7); reasoning (5)	12
Active	Copying (1); highlighting (1); repeating (1)	3
Passive	Listening to reader (35); reading for the group (36)	71
Disengaged	Doing other things (6)	6

During the intervention, learners collaboratively worked in groups in answering all questions on the worksheet. After the group's reader read the question, the members brainstormed providing their ideas, arguing, and supporting their answers with justification. After deliberations and agreement, the learners came up with one answer to represent their group for each question. The groups made a lot of noise as the learners actively worked through the activities mainly in the interactive cognitive mode.

Occasionally, some groups consulted other groups or the teacher. For example, some learners asked the teacher what number of moles (betweeen moles of H_2SO_4 or NaOH) to use calculate the number of moles of products. The teacher responded by asking "*which number of moles between excess and the limiting reactant will you use to calculate the amount of product?*". One learner responded, "*the moles of sulphuric acid from question (b)*". The other learner said, "*Really? Because it is in excess right?*" Yet another learner argued that "*No, we must use the moles of the limiting reactant*". The rest of the learners said, "*Oh yes, the limiting reactant limits the number of moles produced*." The teacher did not provide answers to the learners but instead asked learners probing questions to direct them to the right path.

After each activity, the spokesperson of each group posted the answers for the group on a chart and all learners in the class assessed the responses with the teacher's guidance.

Discussion

The learners' development in problem solving was inferred from their responses in the tests and could be attributed in part to their level of cognitive engagment as they completed POGIL activities during the intervention. The pre-test revealed evidence of learners' poor problem solving competency of stoichiometry questions prior to exposure to POGIL, as inferred from the responses characterised as Novice and Elementary. The post-test results indicate a statistically significant improvement in the problem solving ability. The observed improvement in problem solving competency could in part be attributed to the fact that learners mostly worked in the interactive cognitive mode of engagement of the ICAP framework, collaboratively working through the POGIL worksheets assisting one another, explaining, and justifying their views to solutions of questions. The teachers worked as facilitators by guiding learners to independently work through the worksheets

We argue that the use of a simple activity, like the car model, may have helped learners to develop and scaffold conceptual development from the familiar to the abstract. The analogy of the car helped the learners develop a mental construct of chemical composition, supporting the results of Barke et al. (2009). The development of a rubric for characterising learners' stoichiometry problem solving competence is a novel contribution of the current study and extends the literature on stoichiometry problem solving proficiency (Mandina & Ochonogor, 2018) .

Conclusions and recommendations

The limitations of this study included the short treatment period, and the small sample. Despite these limitations, the study provided valuable insights into how POGIL has the potential to enhance SA learners' problem solving skills through the scaffolded concept development and enhanced cognitive engagement. However, longer periods of exposure to POGIL and implementation of a larger scale comparative quantitative study may provide opportunities to obtain more conclusive results. Science teachers, teacher-educators and subject advisors are urged to consider POGIL in teaching stoichiometry and other abstract science topics. Improved skills in solving problems at higher cognitive levels would lead to improved achievement scores after the POGIL interventions.

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(Chi M. T., 2011)