EVALUATING PROBLEM SOLVING STRATEGIES USED BY GRADE 12 PHYSICAL SCIENCE LEARNERS IN HIGHVELD RIDGE EAST AND WEST CIRCUITS WHEN SOLVING STOICHIOMETRIC PROBLEMS.

Edwin Tigere 1 & Harrison I. Atagana 2
1 Highveld Park High School, Private Bag X 1203, Secunda, South Africa, 2302
2 Institute for Science and Technology Education, University of South Africa, Pretoria.
Email: tigereedwin@tsamail.co.za

Abstract
The aims of the study was to determine the relationship between conceptual and algorithmic problem solving achievement among 12 Physical Science learners in Highveld Ridge East and West circuits, compare the percentage of perfectly and incorrect solutions, problems not attempted and establish the problem solving strategies used by 12 learners. The target populations were 12 Physical science learners in Highveld Ridge East and West circuits; stratified random sampling was used to select schools and 61 scripts from each grade. An achievement test was administered at schools and scored by the researcher. Pearson moment coefficients at alpha 0.05 indicated that the relationship between algorithmic and conceptual achievement was positive but weak. The t-test for paired means indicates that the difference between the algorithmic and conceptual means is statistically significant.

Key words
Conceptual, Algorithmic, Problem solving, Stoichiometry, Achievement

1.1 INTRODUCTION
Problem solving is one of the educational techniques that have been widely investigated. In stoichiometry the aims of problem solving are to clarify and reinforce concepts, principle, laws and to improve learners’ competence in strategies and procedures (Selvaratnam and Canagarama, 2008). A combination of algorithmic and conceptual stoichiometry problem solving will increase the likelihood of attaining these aims.

However, Garfield and Lester (1985) reported that learners perform poorly in conceptual problem solving because of poor conceptual understanding. Potgieter and Davidowitz (2010) added that inadequate and incorrect conceptual knowledge prevents learners from solving stoichiometry problems successfully. However, Caroline et al (2008) found out that there was minimal relationship between understanding of chemistry and problem solving. Lythcott (1990) and Pickering (1990) reported that over-reliance on using algorithms impedes successful problem solving in stoichiometry. On the other hand teachers also find it difficulty to teach stoichiometry (Schmidt, 1990).

1.2 PROBLEM STATEMENT
For the past six years teaching Physical Science the researcher has noticed that learners were struggling to solve stoichiometry problems and has tried using the mole, proportional method, but, the difficulties remained. McFate & Olmsted (1999) found that learners lack problem solving skills and strategies. Bodner (1991) urged that there is a discrepancy between conceptual
understanding and algorithmic problem solving. The National Curriculum Statement Policy in South Africa stipulates that Physical Science learners should be able to solve problems (NDoE, 2002).

However, Mphachoe (2009) after moderating the National Curriculum Statement examination (Physical science paper 2) in Mpumalanga province noticed that learners struggled to solve algorithmically and conceptual stoichiometry problems. Potgieter and Daviowitz (2010) reported that first year tertiary students performed poorly in stoichiometry. This was confirmed by Potgieter, Rogan and Howie (2005) and Potgieter et al (2005). While examining students’ misconceptions in chemical equilibrium Huddle and Pillary (1996) found students unsuccessfully answered chemical equilibrium problems because they fail to apply stoichiometry concepts.

1.3 AIMS AND OBJECTIVES
The aims of this study was to evaluate problem solving strategies used by grade 12 learners in Highveld Ridge East and West when solving stoichiometry problems hence the objectives of this study were:
1. To determine the relationship between conceptual and algorithmic problem solving achievement.
2. To compare the percentage of perfectly correct and incorrect solutions, percentages of problems not attempted between algorithmic and conceptual problems.
3. To identify weaknesses in stoichiometry problem solving that can be remedied during teaching.
4. To judge the impact of algorithmic and conceptual problem solving on proficiency in stoichiometry.

1.4 SIGNIFICANCE OF THE STUDY
Evaluating problem solving strategies used by learners when solving stoichiometry problems will enable educationists to identify problem solving strategies that led to low achievement in stoichiometry hence avoid reinforcing them. In an effort to improve Physical Science Matriculation results, content enrichment workshops are conducted every year at the expense of pedagogical content. The results of this study can convince the Department of Education that content and strategies are integral parts of teaching and learning and teachers should be developed in these aspects. Establishing the relationship between algorithmic and conceptual problem solving strategies and achievement will enable Physical Science educators to choose a better problem solving strategy between algorithmic, conceptual or a combination of the two strategies when teaching stoichiometry.

1.5 ALOGORITHMIC AND CONCEPTUAL PROBLEM SOLVING ACHIEVEMENT
Yarroch (1985) found that the success rate for algorithmic problems solving was 100% and 58% for solving conceptual problems. Pickering (1990) found that 95% of the learners solved algorithmic problems and 40% solved conceptual problems and Nakhleh (1993) found that 30% had high algorithmic and low conceptual problems solving proficiency, 50% had high algorithmic and conceptual problem solving proficiency, 10% had conceptual and low algorithmic problem solving proficiency and finally 10% had low algorithmic and conceptual problem solving proficiency. Alp (2007) and Chui (2002) reported that there was no statistical significant difference between algorithmic and conceptual achievement. BouJaoude and
Barakat (2000) concluded that lack of conceptual understanding causes learners to rely on algorithmic strategies and this was confirmed by Bodner and Herron (2002), and Caroline et. al, (2008). The studies cited above shows that there is no agreement on algorithmic and conceptual problem solving achievement.

1.6 PROBLEM SOLVING IN STOICHIOMETRY
Potgieter and Davidowitz (2010) acknowledged that stoichiometry is poorly mastered by students. However, Glazar and Devetak (2002) found that 46% of students solve stoichiometry problems correctly while 4% of the students did not attempt to solve stoichiometry problems. Davidowitz et al (2010) noted a constant improvement in stoichiometry problem solving. Herron (1975) attributed poor performance in stoichiometry to lack of understanding of the mole concept. Frazer and Servant (1986, 1987) observed that 27% of the students solved stoichiometry problems successfully, and 22% of the students successfully interpreted and used balanced equations correctly. Taber & Bricheno (2009) claimed that learners fail to balance and interpret chemical equations because they lack conceptual resources.

Toth (2004) found that learners use their own strategies to balance chemical equations and solve stoichiometry problems. Toth and Sebestyen (2009) reported that learners who used unidentified problem solving strategies perform poorly. On the contrary, Schmidt and Jigneus (2003) reported that successful problem solvers use their own strategies to solve easy stoichiometry problems and algorithmic strategies to solve difficulty problems. Chiu and Taiwan (2002) reported that the proficiency of learners when solving conceptual and algorithmic problems is the same. On the contrary Gabel and Sherwood (1983) reported that successful problem solvers use algorithmic strategies more frequently than unsuccessful problem solvers and Manson (1994) contradicted the latter by reporting that algorithmic problems are frequently answered correctly by experts and novices.

Greenbowe (1983) found that successful problem solvers in stoichiometry use symbols, microscopic and macroscopic representation to understand the problem and that problem solving is affected by knowledge of facts, working memory load and problem representation. Toth and Sebestyen (2009) found that learners use the mole method and proportional methods in solving easy and difficulty stoichiometry problems and that there was no meaningful difference between in performance. On the contrary Gabel and Sherwood (1983) found that learners who used the proportional method in solving stoichiometry problems performed lower than learners who used the factor-label method, analogies and diagrams. Gauchon (2002), Parchmann et al (2002) and Huddle and Pillary (1996) found that learners fail to determine the limiting reagent because they fail to recognize and interpret numerical relationships in chemical equations. Literature on stoichiometry problem solving does not agree on the effects of conceptual and algorithmic problem solving strategies on achievement. Some of the reasons for low achievement in stoichiometry problem solving in this study are failure to understand the mole concept, interpret chemical equations and lack of formal reasoning.

1.7 RESEARCH DESIGN
A quantitative descriptive study was used in this study because it enables the researcher to establish the relationship between algorithmic and conceptual problem solving achievement without manipulating the natural settings of the participants.

1.8 SUBJECTS
Highveld East and West are circuits in Mpumalanga province. In these circuits are five high schools situated in towns and ten high schools in townships. The Physical Science learners in these circuits are blacks, whites, Indians coloureds and they come from the low class, middle class and high class. There are about 1300 grade 12 learners studying Physical Science in these circuits. At two schools learners studying Physical Science are learners who had attained 50% and above in Mathematics and Natural science in grade 9. At one school, Physical Science is compulsory and at the remaining thirteen schools, learners’ choice to study Physical Science or not. Learners who obtain above 30% at the end of the year are promoted to the next grade; however, some of the learners are condoned to the next grade. At two schools Africans is the medium of instruction, at two other schools English and Afrikaans are the medium of instruction and at the remaining schools taught is the medium of instruction. However English is the second language for the majority of the learners studying Physical Science.

1.9 SAMPLING
Stratified sampling was used to select one town school and three township schools to participate in this study. Random sampling was used to select 61 scripts for scoring.

1.10 INSTRUMENT
1.11 DEVELOPMENT OF THE INSTRUMENT
An achievement test was used because problem solving is an internal process, hence proficiency in problem solving can only be inferred from the problem solvers’ behaviour. The content of the test was derived from the Physical Science national curriculum statement grade 10-12 general guidelines (June 2006). The test had six (6) paired problems. The first part of each problem tested learners’ ability to solve algorithmic problems and the second part tested learners’ abilities to solve conceptual problems. The total marks for the test was 36.

1.12 VALIDITY OF INSTRUMENT
In this case the content of the test was derived from the national curriculum statement grade 10 - 12 (General) and questions were selected using Bretz, Smith and Nakhleh (2004) framework in Bruck and Towns (2009) see table below

<table>
<thead>
<tr>
<th>Question number</th>
<th>Description in terms of Bretz, Smith and Nakhleh (2004) framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Algorithmic multi-step</td>
</tr>
<tr>
<td>1.2</td>
<td>Analysis of pictorial representation</td>
</tr>
<tr>
<td>2.1</td>
<td>Algorithmic microscopic-symbolic conversion</td>
</tr>
<tr>
<td>2.2</td>
<td>Explanation of underlying ideas.</td>
</tr>
<tr>
<td>3.1</td>
<td>Algorithmic multi-step</td>
</tr>
<tr>
<td>3.2</td>
<td>Analysis of pictorial representation</td>
</tr>
<tr>
<td>4.1</td>
<td>Algorithmic multi-step</td>
</tr>
<tr>
<td>4.2</td>
<td>Explaining underlining ideas</td>
</tr>
<tr>
<td>5.1</td>
<td>Algorithmic multi-step</td>
</tr>
<tr>
<td>5.2</td>
<td>Explaining underlining ideas</td>
</tr>
<tr>
<td>6.1</td>
<td>Algorithmic multi-step</td>
</tr>
</tbody>
</table>
6.2 Analysis of data

The test was sent to a Lecturer of chemistry and a Chemistry Doctorate student who is currently teaching Physical science at F.E.T phase. The instrument was adjusted in line with their recommendations.

1.13 RELIABILITY OF INSTRUMENT

The results of the pilot project the results problems were divided into two halves as shown in the table below.

<table>
<thead>
<tr>
<th>Questions in group</th>
</tr>
</thead>
<tbody>
<tr>
<td>First half</td>
</tr>
<tr>
<td>1.1, 2.2, 3.1, 4.2, 5.1, 6.2</td>
</tr>
<tr>
<td>Second half</td>
</tr>
<tr>
<td>1.2, 2.1, 3.2, 4.1, 5.2, 6.1,</td>
</tr>
</tbody>
</table>

The half-split coefficient was 0.58, after applying the Spearman-Brown prophecy the reliability coefficient was 0.73.

1.14 PROCEDURES

Permission was obtained from the Mpumalanga Department of Education and from Principals of four schools where the test was to be administered. The researchers then seek for cooperation from teachers’ grade 12 Physical science teachers from the chosen schools. The researcher discussed with the teachers the aims, the importance of the study, emphasized the need to stick to standard procedures of administering a test, to inform learners of their right to participate in the study and to completing the consent. The test was administered to the participants at their respective schools by their Physical science teachers during the last week of August. At the end of the test, teachers withdrew the papers to avoid contamination. The test was scored by the researcher. A mark was given for each correct answer for both conceptual and algorithmic problems and for algorithm problems two marks were awarded for providing the correct procedure and one mark for an impartially answer. For conceptually questions two marks were awarded providing the correct explanation and one mark for an impartially explanation. No marks were awarded for incorrect answers, procedures and explanations.

1.15 DESCRIPTIVE DATA ANALYSIS

Table 1 below provides the descriptive statistics of means, standard deviations and minimum scores, maximum scores, possible scores and Pearson coefficients.

Table 2: Means, Standard deviations, Minimum scores, Maximum scores, highest possible scores and Pearson coefficients.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Median</th>
<th>SD</th>
<th>Range</th>
<th>Maximum score</th>
<th>Minimum score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algorithmic</td>
<td>43.85</td>
<td>44.44</td>
<td>23.20</td>
<td>83.30</td>
<td>88.89</td>
<td>5.60</td>
</tr>
</tbody>
</table>
The highest scores for algorithmic and conceptual problem solving were 88.89% and 50.00% and the lowest scores were 5.60% and 0%. The means for algorithmic and conceptual problem solving were 44.44 and 22.22 respectively with standard deviations of 23.20 and 10.66. The Pearson moment of coefficient was 0.18 which indicates that there was a minimal relationship between algorithmic and conceptual problem solving achievement among grade 12 in Highveld Ridge East and West.

1.16 INFERENTIAL STATISTICS
The t-test for paired means was used and the results are summarized in table 3 below.

**Table 3: Results of t-test for paired means**

<table>
<thead>
<tr>
<th>t-Test: Paired Two Sample for Means</th>
<th>Algorithmic</th>
<th>Conceptual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>43.86</td>
<td>19.67</td>
</tr>
<tr>
<td>Variance</td>
<td>538.14</td>
<td>113.74</td>
</tr>
<tr>
<td>Observations</td>
<td>61</td>
<td>61</td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>df</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>t Stat</td>
<td>7.94</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>5.96E-11</td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>2.000</td>
<td></td>
</tr>
</tbody>
</table>

p>0.05

The t stat (7.96) is greater than the t critical, which indicates that the difference between algorithmic and conceptual means is statistically significant.

1.17 QUALITATIVE ANALYSIS
Learners were classified on the basis of their algorithmic and conceptual achievements. Scores were classified as low (L) for less than 50% and high (H) for scores above 50%.

- **LC** (Low Conceptual achievement)
- **HC** (High Conceptual achievement)
- **LA** (Low Algorithmic achievement)
- **HA** (High Algorithmic achievement)
Table 3 below summarizes the problem solving categories of the learners in stoichiometry problem solving.

**Table 5: Classification of learners according to problem solving proficiency**

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of learners in grade 12</th>
<th>Percentage of learners</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA and LC</td>
<td>32</td>
<td>52</td>
</tr>
<tr>
<td>HA and HC</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HA and LC</td>
<td>27</td>
<td>44.21</td>
</tr>
<tr>
<td>HC and LA</td>
<td>2</td>
<td>1.03</td>
</tr>
</tbody>
</table>

The category with the highest number of students is low algorithmic and low conceptual, followed by high algorithmic and low conceptual and there are no learners with high conceptual and high algorithmic problem solving abilities.

**Table 5 : Percentages of learners who provide perfect solutions, totally incorrect solutions and did not attempt algorithmic and conceptual problems**

<table>
<thead>
<tr>
<th></th>
<th>Percentage of algorithmic problems</th>
<th>Percentage of conceptual problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perfect solutions</td>
<td>26.78</td>
<td>5.46</td>
</tr>
<tr>
<td>Incorrect solutions</td>
<td>30.05</td>
<td>47.27</td>
</tr>
<tr>
<td>No solutions</td>
<td>10.38</td>
<td>18.85</td>
</tr>
</tbody>
</table>

The percentage of perfectly correct solutions (3 out of 3) for algorithmic problems was higher than the percentage of conceptual problems and the percentage of completely incorrect solutions of conceptual problems was higher than the percentage of algorithmic problems.

### 1.18 DISCUSSIONS

Results shown in table 2 indicate that algorithmic problem solving mean (43.85%) is higher than conceptual problem solving mean (19.66). This indicates that participants performed better in algorithmic problem solving compared to conceptual problem solving. The results of this study confirm the results that were reported by Sawrey (1990), Manson, Shell and Crawley (1997) who reported that novice problem solvers consistently show greater success in solving algorithmic problems than in solving conceptual problems. However, the above results contradict with the results that were reported by Chiu (2001) that conceptual problem solving achievement was higher than algorithmic problem solving achievement.

The results of the t-test indicate that the difference between algorithmic problem solving and
conceptual problem solving is statistically significant. This result confirms the results that were reported by Okanlawon (2008) and Hong (2011) that there is a significant difference in the algorithmic and conceptual achievements.

A weak positive correlation between algorithmic and conceptual problem solving achievements in this study confirms the result by Agung and Schwart (2007) who reported that there is no strong positive correlation between students’ performance on conceptual problems and algorithmic problems. The result also confirms Nurrenburg and Pickering (1987) who found that there was little difference between algorithmic and conceptual problem solving achievements.

In this study 51% and 44% of the learners answered algorithmic and conceptual problems respectively. This result contracts the study done by Mason (1994) who found that learners answer algorithmic problems more frequently compared to conceptual problems. Learners fail to answer problem 1.2, 4.2 and 3.2 revealing that they have poor interpretation of diagrams. This confirms the results of Gabel (1999) and contradicts Gabel and Sherwood (1983) who reported that learners who used learners who used diagrams perform better than those who use the proportional method. Finally, solutions to problem 1.2, 3.2 and 4.1 show that learners have limited understanding of subscripts and coefficients as was reported by Robinson (2002).

1.19 WEAKNESSES
The weaknesses of this study are drawing conclusions from observations made once and that tests make some learners anxious thereby underperforming.

1.20 IMPLICATIONS
Every year the final Matriculation examination test learners to calculate equilibrium constants. These problems require learners to apply algorithmic and conceptual problem solving strategies. As the situation is Highveld Ridge learners are likely to perform poorly in chemical equilibrium. Low proficiency in solving stoichiometry problems will also affect the performance of these learners at tertiary and workplaces.

1.21 RECOMMENDATIONS
This study was cross sectional, it is recommended that the same study be conducted using a longitudinal design. Mphachoe (2009) reported low proficiency in solving stoichiometry problems as well as this study. It is high time to determine the cause of low proficiency in stoichiometry problem solving. Lastly it is recommended that Highveld Ridge East and West circuits should conduct content enrichment as well as pedagogical workshops in stoichiometry.

1.22 REFERENCE
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