

Learners' Performance in Physical Sciences Using Laboratory Investigations

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ABSTRACT One of the goals of science is to promote laboratory investigations (LIs) to improve conceptual development and performance. This study focuses on how learners' performance in physical sciences could improve using LIs in under-resourced schools in South Africa. A quasi pre- and post-test research design was used. A total of 51 Grade 10 learners participated: 25 from one whole class was assigned to an Experimental Group (EG) and 26 from another class to a Control Group (CG). The EG was taught using LIs while the CG the traditional approach. Data on learners' performance were collected using a performance test and interviews were employed to collect data on learners' attitudes towards science. The results revealed that the EG performed better than the CG (T-test, $p < 0.05$), (ANCOVA, $p < 0.001$). Girls in the EG performed better than girls from the CG (Mann-Whitney U-test: $U = 34.50$, $p < 0.05$), suggesting that LIs did not discriminate against gender in this study. Furthermore, the results from interviews indicated that learners from EG exhibited positive attitudes towards science, unlike their counterparts from the CG. This suggests that learners from the EG may have been excited to observe phenomena and to handle apparatus.

INTRODUCTION

Physical sciences as a subject in high schools consists of physics and chemistry parts. Studies by Bevins et al. (2011) show that these are difficult for many learners. Physics part is very problematic in secondary schools and it attracts few learners and the success rate is low (Mattern and Schau 2002). For instance, in England, Osborne et al. (1998) claimed that physics is only taken by learners who do well in the subject. Similarly, learners found that chemistry was difficult and dropped its popularity ranking from fifth to eighth position (Porter and Parvin 2008). In Portugal, learners' difficulty in physical sciences was due to failure to use laboratories properly (Afonso and Leite 2000). Therefore, prospective physical sciences teachers were encouraged to study a module on how to use Laboratory Investigations (LIs) in order to improve learners' performance (Afonso and Leite 2000). This could be done when teachers use laboratory tasks like learning by doing, designing experiments and investigating issues (Ivgen 1997). Laboratory tasks are envisaged to "provide model lessons and experiences, build relevant theory and content knowledge" (Lit and Lotan 2013: 60). Also, learners can be able to "state hypotheses, observe...draw conclusions and... explain why they used a control aquarium tank

in the experiment" (Boaventura et al. 2013: 802). Laboratory experiences are likely to make learners understand and enjoy sciences (Parkinson et al. 1998) and the use of cartoons minimised misconceptions in a chemistry class (Acar and Tarhan 2011; Özmen et al. 2012). Thus, it is important to develop laboratory investigation skills in schools (Cardak et al. 2007).

Many schools in South Africa do not have science laboratories and where they do exist, they are not used effectively (Muwanga-Zake 2008). Jong et al. (1999) indicated that pre-service science teachers construct ideas to teach a subject from their own experiences as learners and develop a positive attitude towards science (Papanastasiou and Zembylas 2004). An exploratory study on how to teach science indicates that learners' attitudes and interests could play a substantial role in their performance (Lee and Burkam 1996). Learners with a positive attitude towards science are more likely to be found in classrooms that use LIs (Myers and Fouts 1992). This implies that positive attitudes towards science may also lead to better performance (O'Connell 2000). For example, learners' performance in problem solving depends on teachers' methods and attitudes towards science (Charles et al. 1987). The challenge in most cases is how to make sure that learners develop positive attitudes towards science. The challenge in Africa as a developing continent has been exacerbated by poor infrastructure (Crawley and

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Black 1992). Nevertheless, there are some successful stories. For instance, in Nigeria there are insufficient laboratory facilities, consequently, secondary school learners are taught physics using guided discovery notes, demonstrations and expository teaching approaches. These methods are highly effective in improving learners' attitude towards physics in such under-resourced schools (Crawley and Black 1992). Under-resourced schools in this study are defined as those schools where features like teaching and learning materials, teaching space and laboratories are missing or are partially present.

Similar to Nigeria's experiences, many rural schools in South Africa do not have access to laboratories or do not use laboratories when teaching sciences (Mji and Makgato 2006). This is supported by a quotation from Mji and Makgato (2006: 260) "One of the points that learners complained about was the lack of laboratory equipment." Also, many learners expressed a similar view as articulated here by Thabang "I think it would be better if when they teach science and physics that they should show us when they ask about sulphuric acid, I don't know what is sulphuric acid, it will just be an abstract thing, that name, when they tell you that when you mix this and that gives you that, you don't know what is that" (Mji and Makgato 2006: 260). Thus, it is clear that South Africa and Nigeria have a challenge in using laboratories to teach science. This makes it difficult for learners in South Africa to perform experiments in an investigation science classroom. Consequently, such schools report a low performance rate in Matric science results (an equivalent of Grade 12) and learners lose interest in physical sciences. Although Matric pass rates in Limpopo, South Africa, increased from 48.9, 57.9, 63.9, 66.9%, in 2009, 2010, 2011 and 2012, respectively, the number of learners studying physical sciences decreased dramatically. For instance, in 2009 the number of learners was registered for physical sciences 220882 and decreased to 180585 in 2011, a decline of 18.2% (Department of Basic Education 2010, 2011, 2012). In order to improve pass rates in sciences, there is a need to use a method that will increase learners' interest and conceptual development. LIs are envisaged to improve learners' performance in science subjects in under-resourced schools and yet they are rarely used in the country.

Purpose of the Study

The purpose of this study was to investigate learners' performance in physical sciences using LIs in under-resourced schools in Limpopo province, South Africa. The study also explored how LIs could improve academic performance and attitudes of boys and girls towards physical sciences.

Hypotheses

1. The use of LIs in under-resourced schools could help learners to improve their performance in physical sciences.
2. LIs could equally improve performance of boys and girls in physical sciences.
3. Learners using LIs will develop positive attitudes towards physical sciences.

Literature Review

Currently, science teachers agree that laboratory work is synonymous with LIs and is indispensable in developing an understanding of science (Ottander and Grelsson 2006; Tan 2008). Hereafter the two terms are used interchangeably. The role of laboratory work in science education has been documented as paying attention to questions for investigations, what is to be done, observed, interpreted, and finally how data is communicated (Lazarowitz and Hertz-Lazarowitz 1998; Toplis 2012). Laboratory work provides learners with an opportunity to experience science by employing scientific research procedures. Thus, in order to attain meaningful learning, to understand scientific theories and their application methods, learning should be done using LIs. Moreover, engaging in practical work should encourage the development of critical thinking skills and create interests in science (Ottander and Grelsson 2006). However, there are concerns about the effectiveness of laboratory work in aiding learners to understand various aspects of scientific investigations (Lazarowitz and Tamir 1994). For instance, a few studies conducted in Nigeria indicate that there are no significant differences in academic performance in schools with adequate laboratory equipment and those that lack such facilities but use guided notes and demonstrations (Jebson and Andy 2012). This may need further studies on a multinational scale.

On the other hand, creative and critical thinking is needed in a science laboratory to develop logical thinking processes (Garrison and Archer 2000). Therefore, LIs could provide a rich context for creativity. According to Raimi (2002), laboratory work in Pakistan improved learners' performance in chemistry. Similarly, Adesoji and Olatunbosun (2008) described how a chemistry workshop using LIs was adequate to enhance learners' performance in chemistry. Researchers in elementary science reform emphasise the need for learners to engage in scientific inquiry (Driver et al. 1994). Engaging learners in inquiry can provide powerful learning experiences where learners not only learn about science content but also gain research skills. Learners gain an understanding of the nature of scientific problem solving (Magnusson and Palincsar 1995). However, in their arguments, these authors did not either consider rural schools which have no access to laboratories or indicate how learners in these schools could be taught science effectively. Although the use of laboratory work appears to be the most effective way to teach science meaningfully, there is a dearth of data on the success of LIs in under-resourced schools in developing countries (Fradd and Lee 1999; Onwu and Stoffels 2005). This study, therefore, will contribute to the literature on how LIs as an active form of learning could be applied in under-resourced schools (National Research Council 1996, 2000) to improve learners' performance in physical sciences (Roth and Roychoudhury 2003).

METHODOLOGY

This study used both quantitative and qualitative approaches. A pre- and post quasi-experimental research design with a non-equivalent control was used. This method was chosen because the EG and the CG consisted of pre-existing whole classes. Semi-structured interviews were used to complement quantitative data, since interviews offer a more complete picture of learners' thought patterns than diagnostic testing alone (Duit and Confrey 1996; Carr 1996).

Research Location/Population

This research targeted a rural school from the Capricorn District in Limpopo, South Africa for the following reasons: (a) learners have

not been exposed to LIs before; and (b) the school is under-resourced in terms of laboratory equipment and performs poorly in Matric science examinations.

Participants

A sample of 51 Grade 10 learners from one under-resourced school, exhibiting low achievements in physical sciences was selected using whole class sampling technique. The EG (Class A) consisted of 25 learners (11 girls: 14 boys), while the CG (Class B) consisted of 26 learners (11 girls: 16 boys). The learners were homogenous according to their classroom test performances and their mean age was 15.

Instruments

The test consisted of 25 multiple choice questions with four possible answers. Learners had to choose the most appropriate answer and provide a reason for the choice made. The test items in the test were assessed by four experts: a physical sciences head of department; and three physical science teachers from the school where the second author was teaching. The Content Validity Index (CVI) was computed using the formula below (Cohen 1960; Brennan and Hays 1992):

$$CVI = \frac{\text{Number of items judged by both judges as right}}{\text{Total number of items in the questionnaire}}$$

An overall CVI of 0.91 was obtained and therefore the instruments were considered to be valid. In order to ensure internal consistency, instruments were piloted to 10 secondary school learners with an educational background similar to that of the study groups. A Cronbach alpha coefficient (α) was computed from the results using the formula below (Cronbach 1951: 299):

$$\alpha = \left(\frac{K}{K-1} \right) \left(1 - \frac{\sum S_i^2}{S_{sum}^2} \right)$$

where:

K = number of components (K - Items);

S_i^2 = variance of K individual items;

S_{sum}^2 = variance for the sum of all items.

Cronbach alpha coefficients were obtained for each item and an overall value of 0.87 was obtained. Any item with a coefficient of ≥ 0.7 was included in the instrument; on this basis five items were found not to be suitable and were

removed from the test. Thus, the final version of the test consisted of 20 items.

Data Collection

Both the EG and the CG were given a pre-test to determine their knowledge before the study. The EG was taught using LIs (interactive) and the CG used the traditional (non-interactive) method according to Roth and Roychoudhury (2003). Both groups were taught for a period of four weeks during the second quarter of 2011 academic year. They both worked on three groups of tasks that were assigned to learners in their respective groups. The only difference was that the EG was taught using LIs (intervention), but not the CG which was taught using traditional teaching approach. Thereafter, a post-test was administered to both groups. This post-test was the same as the pre-test they had completed previously. The only exception is that questions in post-test were interchanged to minimise recognition.

Learners in the EG performed experiments and answered questions requiring them to go through a series of science processes such as searching for information in the library and from Internet. Here are three sample tasks from “Matter and Materials strand” that were used and characterised LIs activities: 1) Learners dissolved sodium chloride and were asked to write a hypothesis. The hypothesis followed the pattern displayed here: *‘If the sodium chloride dissolves in water which is polar, then must be..... because like dissolves in like’, and so forth;* 2) Learners placed a Coca-Cola can in the deep freezer. They removed it from the freezer after 24 hours and observed that there were liquid droplets around it. The learners’ hypothesis followed the format below: *‘If you place a dry can of Coca-Cola in a freezer, then drops of water forms on it because.....’;* 3) Learners placed two burning candles, one tall 6 cm candle and one short 3 cm candle, in a bell jar and covered them. They were asked to predict which candle would go out first and to write down reasons for the outcome (Question adapted from Webb 2010). For the CG, these concepts were explained to learners and no experiment or demonstration was performed. In both groups learners’ parental support was not solicited. Learners in the CG were passive in class and raised no objec-

tions about what they were told to complete the tasks. In order to reduce any harm done by omitting the CG from using LIs, the whole class was taught using LIs after the study was completed.

For qualitative data, interview schedules consisted of three questions: 1) how did you enjoy physical sciences lessons? 2) how did the method of teaching physical sciences assist you in developing interest in the subject?; and 3) how much time do you spend studying physical science after the lesson? These questions were designed by the researchers and checked for face validity by two science lecturers. Thereafter, they were piloted to six learners to determine their suitability. Interviews were conducted with a total of eight learners with similar background (labelled 1-8), 4 from the CG and 4 from the EG (2 Females and 2 Males per group) in order to determine their attitudes. Each learner was interviewed for a maximum of 20 minutes and the interviews were audiotaped.

Data Analysis

Descriptive (mean and standard deviations) and inferential tests (T-test, Analysis of covariance- ANCOVA and a Mann Whitney U-test) were utilised. In both cases, SPSS version 17 was utilised. The differences between the EG and the CG for the pre- and post-tests were analysed using a T-test ($p < 0.001$). ANCOVA was used to determine the impact of the LIs after four weeks of teaching using a pre-test as a covariate. A Mann Whitney U-test was used to determine if there were significant differences between boys and girls in performance after four weeks of teaching. In addition, responses from semi-structured interviews from the two groups (EG, CG) were analysed thematically to identify learners’ attitudes towards science. Audiotaped data were transcribed verbatim and transcripts were analysed using open, axial and selective coding (de Vos 2010). During open coding transcripts were read sentence by sentence to determine key ideas followed by axial coding where key ideas were re-arranged to form sub-themes. Lastly, during selective coding sub-themes were compared to the purpose of the study in order to generate main themes.

RESULTS

The overall results revealed that the EG outperformed the CG. The results of the pre-test

for the EG performance (mean 9.52 ± 2.92 SD) and the results for the CG (mean 7.11 ± 1.95 SD) did not differ significantly (T-test: -0.19 , $p > 0.05$). After teaching for four weeks, the EG performance (mean 10.48 ± 3.2 SD) was again compared to that of the CG (mean 8.59 ± 2.40 SD) and there were significant differences between the two groups (T-test: 4.31 , $p < 0.05$). An effect size of 0.84 and a Cohen d of 0.41 were obtained in favour of the EG. The performance results attained by the girls from the EG (mean 10.22 ± 2.3 SD) were higher than the CG their counterparts (mean 7.28 ± 1.89 SD) (Table 1) and were also better than those of the boys from the EG (mean 8.64 ± 3.38 SD).

Table 1: T-test results of EG and EC before and after (*Significant at $p < 0.05$)

	<i>df</i>	<i>Mean</i>	<i>t</i>	<i>p</i>
EG –CG Before	48	-0.44	-0.19	0.27
EG –CG After	48	2.91	4.31	0.00*

In order to determine if LIs exerted an effect on the EG, ANCOVA was used and the results are shown in Table 2.

Table 2: ANCOVA summary results of EG and CG before and after (Significant at $p < 0.01$)**

<i>Source</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>
Pre-test	24.58	1	24.57	4.23	0.06
Post-test	36.41	1	36.41	6.27	0.01*
Error	273.02	47	5.81		
Total	3845.00	49			

Using pooled data for boys and girls per group, the summary of ANCOVA shows that there were no significant differences between the two groups during the pre-test ($p > 0.01$). However, the results of the post-test indicate that there is a significant difference between the two groups ($p < 0.01$). This suggests that learners using LIs improved their understanding of physical sciences. Thus, LIs reinforced critical thinking and logical reasoning in physical sciences. While the performance of girls from both the EG and the CG did not differ in the pre-test results, results for girls from the EG differed significantly from those of the CG ($U = 34.50$, $p < 0.05$) (Table 3) after four weeks of teaching.

The results show that learners from the EG (taught using LIs) had positive attitudes towards physical sciences but not those learners from

Table 3: Mann-Whitney U-test results of girls performance before and after intervention (*Significant at $p < 0.05$)

	<i>U</i>	<i>Z</i>	<i>P</i>
Girls EG Vs CG before	49.50	-1.03	0.30
Girls EG Vs CG After	34.50	-3.26	0.00*

the CG (taught without LIs). From semi-structured interviews, three themes were identified and these are: 1) lack of enjoyment; 2) lack of interest in science; and 3) time it takes to understand science content. In response to how learners enjoyed physical science all learners from the CG stated that they did not enjoy science at all. Below are a few specific direct quotes from a few learners:

Learner 2: “I do not enjoy learning physical sciences because it is very hard to understand”

Learner 4: echoed learner two by stating that, “I have no desire to continue with physical sciences. I have had enough. I work hard and fail and because of that I hate the subject. Teachers’ explanations confuse me even the more.”

Learner 5: “Physical sciences subject is time consuming. If I want to understand the content I have to spend a lot of time. I may not even pass it. I mean, I cannot cover the content in a given time.”

Learner 6: “I do not like physical sciences because it is really difficult for me. However much time I spend, I get low marks.”

On the other hand, all 4 learners from the EG had positive attitudes judging from their responses below:

Learner 8: “I enjoy the LIs because they make me realize what real science is all about and the observations help me relate to what I read in the text book.”

Learner 7: “I used to read many times without understanding, but after LIs I could understand content after reading once.”

Learner 3: “What makes me like Physical Science is the way our teacher challenges us to think out of the box. You suggest new ways of doing the same experiment. This is why I want to continue to study Physical Sciences. I love it.”

Learner 1: “After the LIs actually you do not need much time to read the content because the content is right in your mind. That is to say, when I learn using LIs approach I understand content much quicker and better than before using LIs.”

DISCUSSION

The purpose of this study was to investigate learners' performance and attitudes in physical sciences using LIs in under-resourced schools. A pre-test was given to both groups (EG and CG) and the results show that there was no significant difference in performance of learners from both groups (T-test, $p > 0.05$), suggesting that learners in the two groups had similar understanding of concepts before instruction. However, in the post-test, the EG performed better than the CG and the differences were significant (T-test, $p < 0.05$) (Table 2). An effect size of 0.84 was obtained, suggesting large positive effects for the EG and Cohen d of 0.41 obtained was greater than (> 0.35), suggesting a large gain (Cohen 1988) for the EG. Therefore, Hypothesis 1, that LIs in under-resourced schools would help learners to improve learners' performance in physical sciences, cannot be rejected. The performance of girls in the EG (mean 10.22 ± 2.3 SD) was higher than the CG their counterparts (mean 7.28 ± 1.89 SD) (Table 1) and were significantly different ($U = 34.50$, $p < 0.05$) (Table 3). Therefore, Hypothesis 2, which states that LIs could equally improve boys and girls' performance in physical science, cannot be rejected. This implies that LIs did not discriminate against gender in this study. Similarly, findings reported from earlier studies show that "girls benefit from complex problems, longer wait-time, authentic assessment" (Beisser 2005: 18) and these are part and parcel of LIs. Our results concur with Raimi (2002) study in Pakistan which suggested that laboratory work positively affect learners' performance in physical sciences. Furthermore, Adesoji and Olatunbosun (2008) argued that learners tend to understand and recall what they see more than what they hear and this improves learners' performance. After four weeks of teaching, there was a significant difference in performance of boys and girls in the EG ($p < 0.05$) when compared to those in the CG. Therefore, Hypothesis 2, which states that LIs could improve both boys and girls' performance in physical science, is accepted. These results support earlier findings of Cardak et al. (2007) who argued that LIs using cooperative learning improved performance of all learners regardless of gender. These results are not surprising because it has been recently reported that strategies focusing on learners are

successful in narrowing the achievement gap between boys and girls in physical sciences in high schools (Baker 2013; Michael 2013). In addition, learners benefit through engagement with concepts especially when they do practical work through "interactions, hands-on activities, and application in science" (Hampden-Thompson and Bennett 2013: 1340).

Traditional teaching used in the CG did not make learners enjoy physical sciences and their attitudes, after teaching using traditional approach, were negative towards the subject. This might have been due to the expository approach to abstract content in science classes. It is no wonder learners spent a lot of time to understand science content. Conversely, LIs improved their understanding of science concepts and this ultimately improved the quality of science education. Learners claimed to have spent less time to understand science content; they enjoyed science lessons and developed a desire to continue studying physical sciences in future. Thus, their attitudes formed a vital part of learning science and developed traits such as positive attitudes, motivation, and genuine interest in studying science. These findings are in agreement with Dalgety et al. (2003) and Covington (2000) regarding the importance of attitudes and motivation in science, respectively.

Considering learners reasoning during the post-test, the EG developed a clear conceptual understanding of scientific procedures but not those from the CG. The conceptual understanding exhibited by the EG is in agreement with Lazarowitz and Tamir (1994) who attributed high performance and positive attitudes to laboratory work. The development of positive attitudes has been reported in cognitive, behavioural and affective domains (Ajzen 2005). In this study, semi-structured interviews were intended to uncover the affective domain by seeking learners' emotional feelings regarding Physical Sciences (Rajecki 1990). Learners from EG were positive while learners from the CG exhibited negative attitudes towards Physical Sciences. These findings are not surprising because LIs involved tasks that appealed to emotions and raised contextual issues unlike in the traditional teaching method. Although much time was spent on experiments in LIs classes, it made learners understand concepts much better than before the lesson. This is why some learners suggested that it took them a shorter time to read and under-

stand concepts in physical sciences than it was reported from the CG where LIs were not used. These findings concur with Kidman (2012) where LIs as “undirected activities” were used and learners developed better understanding of science concepts in a shorter time than those who did not use LIs. Learners from the EG are likely to acquire sound knowledge about the natural world that is considered difficult to understand. Thus, scientific investigation “requires persistence and often involves disappointment, frustration, difficulty and failure as well as success” (Edgar 2013: 147).

RECOMMENDATIONS

If learners are to improve their attitudes towards physical sciences, time allocated in secondary schools for a lesson using LIs needs to be increased beyond one hour. Maybe science should be done twice in a week and not once. Some limitations of this study are the small sample (N = 51) and the gender imbalance. Thus, findings from this study cannot be applied to the rest of the province and indeed the country. However, the study has far reaching implications in learning science regarding how to improve learners' understanding of science concepts using LIs in under-resourced schools. Therefore, more studies are recommended to explore learners' performance and attitudes in under-resourced schools where sharing of facilities during experiments are the norm.

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