

Effect of Problem-Based Learning on Students' Achievement in Chemistry

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Abstract
The study investigated the effect of problem-based learning on students' achievement in chemistry. Learners' low achievement in Science in South Africa has been a concern to government, stakeholders, school principals and parents over the years as a result of poor teaching techniques, students' attitudes, lack of teaching and learning materials, teachers' pedagogical skills etc. Several studies, for instance Monitoring Learner Achievement (MLA) project conducted by UNESCO and UNICEF have shown no improvement in the performance of South African students in Mathematics and Science. Quasi-experimental design was employed for the study. 101 equivalent students were selected for the study using pre-test. The control group was taught with the traditional lecture method whiles the experimental group received instruction with PBL. Independent T-test was used for the analysis. Results showed that there was significant difference ($p < 0.05$) in chemistry achievement of students between control and the experimental group while there was no significant differences in the before the study. The results show that PBL is an effective way for to teach chemistry so as to improve students' critical thinking and problem solving skills.
Keywords: Chemistry, Problem-Based Learning, Critical thinking, Traditional lecture, Achievement.

1. Introduction

The teaching and learning of science has seen various transformations which gives teachers and students opportunities to develop positive attitudes towards science as a subject and to make learning of science less stressful but more practicable and meaningful (Hodson,1998; Geddis, 1993). The student must not only learn to understand the concepts of science but use the scientific inquiry to develop the ability to think and act in ways that are related with inquiry. The inquiry process involves asking questions, planning and performing investigations using required tools to collect data (NRC,1996, p.105). Learning science in the 21st century aims at training students to be able to understand concepts, develop process skills and also develop thinking abilities to be able to transfer knowledge (Department of Basic Education, 2011, p.4). The South African Curriculum and Assessment Policy Statement (CAPS) aims to produce students to be able to design and investigate, classify, hypothesize, infer, observe interpret, predict and make conclusions (Department of Basic Education, 2011, p.5). Teachers are to equip learners with knowledge, skills and values that help in meaningful participation irrespective of intellectual ability, race, gender, and socio economic background (Department of Basic Education, 2011, p.4). This could be achieved by encouraging students to engage in an active learning, rather than rote learning. Learning of science seems to promote knowledge and skills in through scientific inquiry and application of scientific knowledge (Department of Basic Education, 2011, p. 5).

However, in the recent past in South Africa, there has been a significant trend in students' failure in physical sciences in the National Senior Certificate (NSC) final examination, which is published in the bulletin of Department of Education. Particularly in the KwaZulu-Natal province, the decline in students' performance has been quite worrying over the past few years. In 2013, 50,332 wrote the NSC examination and the pass rate for physical science was 66.4%. In 2014, 45,143 candidates sat for the examination and 55.8% passed. Out of the 50,163 candidates who wrote the examination in 2015 only 25,984 passed representing 51.8% (National Certificate Examination School Performance Report, 2015). It could be seen that there has been a decrease in the pass rate in Physical Science in the NSC examination. Meanwhile, the minimum requirements to be admitted to offer diploma and bachelor's degree study at a higher education institution, is purged at a grade of 40-49% and 50-60% achievement in Physical science respectively. Most students do not meet the minimum requirement to further their education in the universities as a result of poor performance in Physical sciences in the NSC examination. This has become a worry to school principals, teachers, subject advisors, parents and all other stakeholders as to the real cause of the problem and strategies of addressing them.

Also some parents have little knowledge about Physical science yet they choose it as their preferred subject for their children without considering the child's interest and performance in the science subjects in the previous classes (Mji & Mbinda, 2005). Most parents are not educated so they have no idea about the subjects but want their children to become nurses or doctors so they impose subjects, which have positive influence on their children's achievement. Another major contribution to the failure in poverty on the part of parents. Most parents find it difficult to provide school materials like textbook, reading materials and sometimes-good meals for their children (Pillay, 2004; Mji and Mbinda, 2005).

Other challenges including the lack of resources such as teaching aids, large class size; pupil-teacher ratio and materials for the practical lessons tend to force teachers to deliver the lessons theoretically (Edward and Fisher, 1995; Hanushek, 1997). Again, due to time constraints most teachers ignore the practical lessons (Ogula & Onsongo, 2009). This is so because the syllabus is structured in such a way that a certain scope must be covered before the quarterly examinations and considering the fact that practical lessons take a lot of time to organize and deliver, they prefer to teach it theoretically. Most students also perceive Physical science as a difficult subject and so are they are not committed to study the subject which has resulted in the development of negative attitudes towards the subject (Legotlo, Maaga & Sebego, 2002). In addition to the above, other factors responsible for students' poor performances in science are lack of content knowledge by teachers and the type of teaching method used (Van der Berg, Taylor, Gustafsson, Paul, & Armstrong, 2011; Kriek & Grayson, 2009). The have little knowledge about the content and other practical aspects of the subject, and so it makes it difficult to teach the students. To improve the performance of students in Physical Science, a more engaging teaching strategy should be employed by the teacher.

Among these strategic teaching methods is the Problem based Learning (PBL) approach. This paper focuses on problem-based learning as a teaching strategy and how it can effectively be used to increase students' achievement in physical science. The research specifically assesses how PBL as a method of instruction can be effectively used in teaching chemistry in high schools.

2. Literature

2.1 Problem-Based Learning (PBL)

Problem based learning (PBL) can be defined as a type of learning which involve problems that give students opportunity to design an investigative activity using problem-solving to arrive at a conclusion (Thomas, 1999). PBL as an instructional method helps students to use open-inquiry approach in learning to apply scientific knowledge in real life situations (Ketpichainarong, Panijpan & Ruenwongsa, 2010) unlike the traditional method where students become passive in the teaching process that does not promote problem-solving and cognitive skills (Ronis, 2008). PBL involves an experimental learning process that is composed of data collection, investigation, observations, explanations and drawing conclusions (Torp and Sage, 2002; Bell, 2010; Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991). When students are engaged to learn through the inquiry process it enables students to build confidence in themselves. The inquiry learning seems to contribute to the understanding of scientific concepts (Duggan & Gott, 2002) which can be applied in everyday life context. Hoffman and Ritchie (1997) stated that students who are exposed to PBL are able to transfer the knowledge and skills in real life situations. The use of PBL is found to enhance self -regulatory skills in students thereby improving academic performance (Sungur & Tekkaya, 2006). The students are able to explore other ways of learning through the use of PBL. The use of the PBL strategy in teaching also helps to stimulate students understanding on how to find information that are linked to the problem and this increases their thinking ability. The teacher only guides the students throughout the learning process whilst the students take responsibility of their own learning to come up with a solution (Ngeow & Kong 2001) Furthermore, it motivates students to learn and develop independent skills to enable them solve problems and face challenges in their real life situations. The use of PBL puts the students' responsibility in their own work can enable teachers to monitor students understanding and the development of a self-regulated learning (Karabulut, 2002).

Notwithstanding, the teaching of science using PBL seems to have some challenges such as lack of teaching aids, inadequate laboratory equipment, lack of textbooks, large class size, teachers' attitudes towards science, and the pedagogical skills of teachers have been some of the setbacks for effective implementation of PBL (Lockhead & Verspoor, 1991). Jones (1996) observed that, setting questions to evaluating students' achievement in PBL becomes cumbersome and as such the assessment should be planned well in advanced. Also, students lack the necessary skills to perform the inquiry process and thus become demotivated through the activities (Edelson, Gordin, & Pea 1999).

2.2 Implementing problem-based learning in the classroom

PBL as a student-centred pedagogical learning involves students put into smaller group to discuss a challenging problem with the aim of finding solution to the problem. Most teachers have been conversant with the traditional method and efforts to modifying it has not been easy. The teacher plays a key role in the PBL instructional process and that the teacher should adopt to new ideas and strategies other than the traditional method, which demotivates the student's abilities in the inquiry process. In the implementation of PBL the students are given a complex problem to solve and the necessary guidelines that will assist them in solving it (Alexander, McDaniel & Baldwin, 2005). The students work in smaller groups to critically discuss the problem and possible ways of exploring and reflecting the problem as well as content (Rideout, 2001). Rosing (1997), explained that students in a PBL classroom try to look for information, access learning material and share ideas among themselves while working in small groups.

One of the roles of the teacher is to guide the students through questioning that will direct the students to find possible solution to the problem. The students make reflection of the problem through the inquiry process by the application of strategies that leads to the problem (Amador, Miles & Peters, 2006). The students in the group go through several steps to solve the problem through observations, predictions and drawing conclusions based on assumptions (Bell, 2010; Blumenfeld et al., 1991). Greenwald (2000), in implementing PBL suggested that the students should be asked open-ended questions that relates to the problem, find possible solutions through problem-solving activities, analyse data using the guided questions, and finally assess problem solving skills and critical thinking skills of students as a way of knowing how much knowledge students have acquired.

2.3 Successful Implementation of Problem-Based Learning

Several researchers have affirmed successful implementation of problem-based learning in the classroom. Cockrell, Caplow, and Donaldson (2000) concluded that there was increased in student's perception of PBL instruction since it enables them to fosters transfer of knowledge. PBL is effective compared to other pedagogical approaches since it facilitates student's critical thinking and problem-solving skills since students are able to apply theory into practice (Cooke & Moyle, 2002).

Aaron, Crocket, Morrish, Basualdo, Kovithavongs, Mielke and Cook (1998) found a higher examination scores in students who enrolled in PBL class as compared to traditional method and recommended that the type of questions asked should relate to the concept and have dispersed knowledge. Gallagher, Stepien, Sher and Workman (1995) reported that, PBL was successful in teaching ecosystems in fifth grade science and a higher performance in the test results as compared to the traditional instruction. Ljung and Blackwell (1996) found positive transfer of knowledge after enrolling in a combination of problem-based and traditional model program. The students passed in English, history, and mathematics after been enrolled in the program. PBL enables students to improve critical thinking skills after analysing a problem to find solution (Shepherd, 1998; Tretten & Zachariou, 1995). This is due to the positive attitudes towards learning and problem solving abilities, which they are exposed to. Zhou, Huang and Tian (2013) concluded that tasked-based learning improves student's analytical skills and ability to personalise learning. Students are able to evaluate and infer into contents learnt while making reasonable conclusion. With this, a habit of mind is promoted among students, which increase scientific literacy among learners.

According to Boaler (1997), students that enrolled in problem-based learning attained a higher grade in national examinations in UK and that significant number of three times students taught through a problem-based school passed the national standardised examination than traditional school students. These findings confirmed that problem-based learning has significant impacts on students' problem solving skills and attitudes towards learning.

3.0 Method

3.1 Participants

The selected sample size consists of 102 students selected from five schools and each from five districts in the KwaZulu-Natal province in South Africa using convenience sampling. The students were selected randomly into the control and the experimental group with each group consisting of 51 students. The students in the experimental group were taught using the PBL strategy whiles the students in the control group were taught with the traditional lecture method of teaching in a 3-month period i.e. January to March 2015.

Before the study began, a pre-test experimental design for both the experimental and control group was conducted to assess their problem solving, critical thinking skills and also their prior knowledge on the concept. The students were then introduced to concepts of rates of chemical reaction, reactions of organic compounds, chemical equilibrium, acid, bases, and salts before experiment to ensure that they gain a fair idea of what they are supposed to know. All the necessary information about the concept ie. materials and instructions and procedures for the experiments were given and explained to the students. The students in the experimental group were guided to construct their own knowledge during and after the lesson with the teacher acting as a facilitator by asking students probing questions that will enable them to be on track. The rubrics were also given to students that guided them as to what is expected of them and how they are to go about it.

3.2 Data Collection and Analysis Methods

The standardized grade 12 questions that relates to the content under study from the quarterly Physical Science examination organized by the KwaZulu-Natal Department of Basic Education was used to collect the data. The pre-test and post-test was used to assess the students' skills of analysis, evaluation and inference to examine whether there will be any significant differences in their performance. The data was analysed using the SPSS (version 23). Finally, the independent sample t-test analysis and paired sample t-test were used to compare the scores of the students before and after PBL instruction.

4.0 Results

Selecting control and experimental groups

Table 1: Independent T-test with Equal Variances not assumed

Groups	Test	Mean	SD	df	t - value	p – value
Control group	Pre-test	16.47	7.404	100.00	0.894	0.657
Experimental Group	Pre-test	15.18	7.213			

Table 1 and appendix A shown that the pre-test mean scores of the control group and the experimental group as 16.47 (*SD* = 7.404) and 15.18 (*SD* = 7.213) respectively. Also, there is no significant different, t (100) = 0.0894, p = 0.657, $p > 0.05$ between the performance of the two groups. This showed the control and the experiment groups were equivalent. The mean score of the post-test in the experimental group was higher than in the pre-test. To determine whether there is difference in chemistry achievement of students between the control and experimental groups, it was hypothesized that: There is no difference in chemistry achievement of students between control and experimental groups after the post-test.

Table 2

Independent T-test with Equal Variances not assumed

Groups	Test	Mean	SD	df	t - value	p – value
Control group	Pre-test	19.98	7.279	100.00	-9.899	0.001
Experimental Group	Pre-test	31.76	4.394			

Independent t-test with equal variance assumed analysis showed that there was a significant difference, t (100) = -9.899, p = 0.01, $p < 0.05$ in chemistry achievement of students between control and the experimental group. Therefore, the stated hypothesis was rejected. Again, post-test means were 19.98 (*SD* = 7.279) for control group and experimental group 31.76 (*SD* = 4.394) as shown in Table 2 and appendix B. Hence, there was a significant difference in achievement between students exposed to the use of PBL instructional approach and those exposed to the traditional instructional approach of teaching chemistry.

5.0 Discussion

The results show a significant difference in the achievement between the students' performance in the post- test after they were exposed to PBL and traditional instructional approach of teaching chemistry ($p < 0.05$)**.** The students in the experimental group performed very well after the study as compared to the control group. It shows that the student's problem solving skills and thinking abilities had improved when the PBL instructional method was used in teaching Chemistry (Boaler, 1997; Cooke & Moyle, 2002; Shepherd, 1998). A good instructional strategy should motivate students to make them understand and reflect on what content they have been exposed and help to develop their critical thinking and problem-solving skills (Iurea et al., 2011; Tretten & Zachariou, 1995). With this, PBL can improve analytical skills through evaluation and inferences of data (Zhou et al., 2013). In a typical PBL classroom, students solve problems as they go through the inquiry process in a real-life context. When students engaged in PBL, teachers encourage them to explore possibilities, invent alternative solutions, collaborate with other students, try out ideas and hypotheses, revising their thinking, and presenting their best solutions. Hands-on activities provide students with opportunities to engage in exploration and make meaningful conclusions (Thomas, 1999; Zhou et al., 2013).

6.0 Conclusion

PBL used for teaching and learning of science provides a means for solving scientific problems, which makes the student to be accountable for their own knowledge. PBL helps to develop students' process skills, thinking abilities and also a positive attitude towards learning of science. Moreover, the use of PBL for learning science creates an opportunity for students to identify their strengths and weaknesses throughout the learning process. It is believed that PBL is a student-centred, which prepares learners to relate scientific concepts to real life situations and that it can be adopted for the teaching and learning of science. The use of PBL as a teaching and learning strategy can improve students' performance in physical science if relevant factors such as teaching aids, large class size, subject teaching qualification, teaching experience can be addressed to and it will impact on learner achievement. It can be concluded that PBL as a student-centered approach is effective in the teaching and learning of Chemistry to improve students achievement.

7.0 Suggestions for further study

In this study, some difficulties were encountered during the experimental procedures because of faulty equipment and chemicals, which resulted in some errors in the expected results. In addition, the students could not understand the procedures and rubrics given due to limited time so an alternative method is to prepare adequately well in advance to check that all the equipment and chemicals are in good condition. Furthermore as a recommendation, the experimental procedure should be well explained to enable students' get proper understanding of experimental procedure. The study recruited only five high schools in one of the districts in the KZN province. This was due to financial constraints and time; as a result, a study can be done recruiting more students from different districts in KZN province or other parts of South Africa.

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