The Impact of Problem Based Learning on Learners' Academic Achievement in Chromatography and Science Learning Activation

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Abstract: **This study explored the impact of problem-based learning on learners' academic achievement in chromatography and science learning activation. The study was grounded in the constructivism theory of learning and involved two grade ten classes studying Chemistry 5054 at Nyamphande Boarding Secondary School in Petauke, Eastern province, Zambia. The two classes had 92 learners. The study adopted a quasi-experimental design and mixed research method. The experimental group was instructed via Problem-based learning while the control group was taught using Structured Inquiry-based science education approach. Before the instructions, a chromatography achievement and problem-solving skills test was administered to test for equivalency. Achievement was assessed using results from a chromatography achievement and problem-solving skills test while the one that related to science learning activation was assessed using results from a questionnaire. A t-test was used to compare achievement of the experimental and control groups at 95% confidence level while science learning activation data was analysed descriptively by computing frequencies and percentages. Results and findings obtained both from the achievement test and a science learning activation questionnaire survey revealed that problem-based learning approach contributed positively to learners' achievement and science learning activation.**

Results of this study suggest that learners in the experimental group were highly activated in fascination in science, moderately activated in values, competency beliefs, science identity and STEM career preference while they exhibited low activation in scientific sense making. Learners in the control group also showed improvement in achievement but not as much as those in the experimental group. The results revealed that Problem-based learning had a positive impact on learners' academic achievement and science Learning Activation.

Keywords: Problem-based learning, science learning activation, chromatography and achievement.

I. INTRODUCTION AND BACKGROUND TO THE PROBLEM

This world is changing rapidly and presents new challenges and demands on our education system. This calls for change and improvement in the preparation of learners for productive functioning in the continually changing and highly demanding environment (Bar-Yam et al, 2002). If learners are to succeed, they need to have not only knowledge but also the values, attitudes, skills and competences which will enable them to make the best use of their learning.

Zambia's curriculum has been revised in line with the principles of outcome based education that seek to link chemistry taught in class to real-life experiences. The curriculum identified six competences and these are; critical thinking and problem-solving skills, communication skills, self-management skills, cooperation skills, creativity and innovation skills and Entrepreneurship (CDC, 2013).

Mastery of these competences requires the use of teaching approaches which attract, sustain learners' interest and connect school learning and real world. Science education research studies carried out in recent years emphasise that constructivist learning theory provides a useful and functional framework from which to attain the goals of science education and brings new practices to instruction (MEB, 2006). According to Schulte (1996) Constructivism says that learners bring their personal experiences into the classroom and these experiences have a tremendous impact on learners' views of how the world works. Learners come to learning situations with a variety of knowledge, feelings, and skills, and this is where learning should begin. This knowledge exists within the learner and is developed as individuals interact with their peers, teachers, and the environment. Learners' construct understanding or meaning by making sense of their experiences and fitting their own ideas into reality.

Problem-based learning (PBL) is one of the Constructivist teaching methods and makes use of authentic tasks. Problem based Learning has been recognised as a significant improvement to teaching (Boud and Feletti, 1991). This is because PBL provides learners with opportunities to develop conceptual and practical skills and practically apply this as they process knowledge and information from various sources.

Barrows (1980) defined Problem-based learning as "the learning that results from the process of working toward the understanding or resolution of a problem". Problem-based learning (PBL) is an instructional method that challenges learners to "learn to how learn," working cooperatively in groups to seek solutions to real world problems. These problems are ill-structured and complex and they are used to engage learners' curiosity and initiate learning the subject matter. PBL prepares learners to think critically and analytically, and to find and use appropriate learning resources (Duch, 1995)

Research has revealed that individuals with very little familiarity with science concepts can learn new ideas using the PBL structure and that the same problem can also help experienced science learners with a high degree of prior knowledge refine their understanding and learn to better explain the mechanisms for scientific phenomena (Parker and Eberhardt, 2018).

The critical factor in the success of PBL is the problem itself (Duch, 1995). Unfortunately, problems presented in a traditional class are not close to what learners encounter in real life situations, they are well-structured and not connected to what learners experience in their environment. Problems in the real world are ill-structured with multiple solutions and no one way of solving them. When a problem is well-structured learners are less motivated and less interested in the development of the solution (Savery, 2006).

A good problem is one that engages learners' interest to probe for deeper understanding, encourages learners to function as a team and connect previous knowledge to new concepts. Since a problem is the starting point in PBL, learners are expected to learn to develop basic problem-solving skills and acquire knowledge through interaction with others. (Phungsuk et al, 2017). In problem-solving, the interest is not in one correct solution but in how to use information from different sources to come up with multiple solutions. The process leading to solutions is more important than the correct solution. This allows learners to be successful in ways that have not been available to them in traditional approaches (Lambros, 2002).

Jonassen(2010)(as cited in Mataka, 2014)claims that problem solving is the ultimate goal of education because it makes knowledge more relevant to learners, and it is easier to retain knowledge that was used in an authentic environment. Problem solving is a process of working towards a solution or solutions to a problem. According to Loyens, Kirschner, and Paas (2011) some problems do not need to be solved but the goal may be to explain or understand the problem in terms of its underlying mechanisms. The aim of PBL is to teach learners how to analyse the problem at hand, to assess the importance of various pieces of information, and to decide which information should be used to understand, explain, or solve the problem and plan subsequent study actions. Problem-solving skills are the processes used to reach the solution to a problem.

Polya (1957) identified four major problem-solving skills; understand the Problem (identifying the problem), Devise a plan (planning), Carry out a plan (Plan implementation) and Look back (Reflections).

Infusing real-life situations in teaching and learning makes chemistry easy to understand and easy to learn. It stimulates Science learning activation and gets the learners excited and involved. Dorph, Cannady and Schunn(2016) defined science learning activation as a set of dispositions, skills, and knowledge that commonly enable success in proximal science learning experiences and are in turn influenced by these successes (That is they form short-term positive feedback loops to produce long-term outcomes). There are four dimensions of science learning activation: fascination, values, competency beliefs, and scientific sense making (Dorph, Cannady, Bathgate andSchunn, 2017).

Fascination: Dorph et al (2017) defined Fascination as 'the emotional and cognitive attachment that the learner can have with science topics and tasks that serve as an intrinsic motivator towards various forms of participation".

Value: The extent to which an individual thinks science is useful to him/herself, families and communities. When a learners attaches high value to the science content learned they learn to care and they then have the energy they need for learning more about it and making it part of their lives(Fink, 2003).

Competency beliefs: The learner's beliefs in his/her abilities in performing a given scientific task. Competency beliefs include self-assessment on the ability to achieve desired outcomes and can also reflect micro-level assessments of perceived skills and abilities needed to complete a task (Hoffman, 2015).

Scientific sensemaking: The extent to which learners are engaged in science-related content and recognise that science is not a series of facts, but a continuous application of a set of practices that are used in search of deep and logical understanding of natural and physical phenomena (Schunn, 2016). This helps learners to perceive the world the way scientists see it and do their work by observing phenomena, generating questions, predicting outcome and generalising results and share their findings (Miller, 2017).

II. RESEARCH OBJECTIVES

This study was guided by the following three objectives;

a. To find out the impact of Problem-based learning on learner achievement in Chromatography and problem-solving skill.
b. To establish the difference in mean scores between the intervention and control groups.
c. To find out the impact of Problem-based learning on Science learning activation.
d. To investigate if there is a relationship between learners' achievement and Science learning activation.

III. RESEARCH METHODOLOGY

The research has a mixed method research design and the quasi-experimental method with "two-group pre-test-post-test design" was used. This study was carried out with 92 grade 10 learners of Nyamphande Boarding Secondary school in Petauke, Eastern Province. Research participants were conveniently selected as there are only two grade ten classes (10A and 10B) at Nyamphande Boarding secondary School and they were assigned to the experimental and control groups using simple random sampling. The used instruments in this study were Chromatography achievement and problem-solving skills test (CAPSST) and Science Learning Activation questionnaire (SLAQ). The two instruments were administered to both groups as a pre-test and post-test. The participants went through PBL process using real-life problems with a study topic "Chromatography".

3.1 Intervention

The intervention was the teaching of chromatography using Problem-based learning method over a period of 4 weeks. The lessons followed the PBL process schema adapted from Lambros (2004). During lessons, learners were divided into small groups (of 4 -5 learners).

During the creation of the two problem scenarios below, the researcher made sure that they were connected to real-life problems and the role of learners were clearly stated. The role play would give learners a job title and job description that they would adopt throughout the PBL lesson. The problem scenario should be presented in such way that learners are encouraged to search for more information on the topic (VISTA, 2014).

One of the aims of chemistry taught at secondary school level is to provide, through well designed studies of experimental and practical Chemistry, a worthwhile educational experience for all learners, whether or not they go on to study Chemistry beyond this level and, in particular, to enable them to acquire sufficient understanding and knowledge to recognise the usefulness, and limitations, of scientific method and to appreciate its applicability in other disciplines and in everyday life(MOGE, 2013). Problem scenarios in PBL are directly related to what learners experience in their daily lives and this enables them to appreciate and value chemistry.

3.2 Problem Scenario 1

You are a Food scientist (chemist) working for Zambia Bureau of Standards (ZABS). It has been discovered that a lot of manufacturing companies producing sweets are not using authorised food dyes, ZABS inspectors have collected samples from three (3) sweet manufacturing companies.

As a Food Scientist (chemist), you have been tasked to research and propose appropriate materials that are suitable for your investigation and determine whether the samples collected were coloured using the authorised food dye by means of comparing to the standard food dye provided in your laboratory.

3.3 Problem Scenario 2

You are a Forensic scientist (Chemist) working for Zambia Police Service in the Forensic Science Department. There are reports from Nyamphande Boarding secondary School that there is someone who has been collecting money for School and Boarding fees from unsuspecting learners by false pretense. This person has been issuing receipts with a forged signature for the School Accounts Assistant. The School management conducted a thorough screening of receipts issued to all grade eights and discovered a number of receipts whose serial numbers did not appear in the receipt book which the Accounts Assistant was using in the period during which the crime was committed.

Fortunately, among the forged receipts there was one receipt which was issued the very day the screening was done. The learner was asked to identify the person who issued her the receipt but unfortunately she failed. The School Management managed to identify three suspects and collected pens from them which were suspected to have been used in the crime.

As a Forensic Scientist, you have been tasked to research and propose appropriate materials that are suitable for your investigation and determine which pen was used to commit this forgery crime and finally identify the culprit.

To work on problem scenarios, learners went through the PBL Process Schema adapted from Lambros (2004). This requires learners to be able to; list facts from the problem scenario, list all information they would like to have to better understand the problem (need to know), identify learning issue, come up with a plan of action in order to address the learning issues and finally learners come up with ideas or hypothesis about how to resolve the problem and it may require the development of new learning issues list.

3.4 Data Collection and Analysis Method

Data on knowledge and problem-solving skills was collected using a Chromatography Achievement and Problem-solving Skills test (CAPSST) while data on Science Learning Activation (SLA) was collected using a Science Learning Activation Questionnaire (SLAQ)The data collected was analysed using Statistical Package for Social Sciences (SPSS version 20) software by adopting descriptive and inferential statistics. Questions 1and 2 were analysed using t-test at α-level 0.05 while questions 3 and 4 were analysed using descriptive statistics and qualitative analysis.

IV. RESULTS

4.1 Test for equivalency between the experimental and control groups

In order to test for equivalency between the control and experimental groups, independent t-test at 0.05 α-level was conducted. The results are in table 4.1.

Table 4.1: Independent T-test with Equal Variances not assumed.

Groups	Test	N	Mean	SD	df	T-value	P-value
Experimental	Pre-test	41	10.29	5.524	74.888	.797	.428
Control	Pre-test	51	9.45	10.583			

Table 4.1 shows the pre-test mean scores of the control group and the experimental group as 10.29 (*SD* = 5.524) and 9.45 (*SD* = 4.347) respectively. The t-value for 74.888 degrees of freedom was 0.797, p-value = .428. The p-value is greater than the critical value (0.05). This means that there is no significant statistical difference between the achievements of the two groups in the pre-test. This showed that the control and the experiment groups were statistically equivalent.

4.2 Test to establish the difference in achievement between the intervention group and the control group

The difference in the means of the two groups (27.84) was substantial in favour of the experimental group. In order to test whether the difference was statistically significant between the control and experimental groups, independent t-test at 0.05 α-level was conducted. The results are in Table 4.2.

Table 4.2: Independent T- Test with assumed equal variance

Groups	Test	N	Mean	SD	df	T-value	P-value
Experimental	Post-test	41	62.00	10.583	88	12.994	.000
Control	Post-test	51	34.16	9.720			

Table 4.2 shows the post-test mean scores of the experimental group and control group as 62.00 (*SD* = 10.583) and 34.16 (*SD* = 9.720) respectively. The t-value for 88 degrees of freedom was 12.994 and p -value was .000. The p-value is less than the critical value (0.05). Hence, there was a statistically significant difference in achievement between learners taught using Problem Based learning and those taught using structured inquiry-based science education method. Therefore, we reject the null hypothesis which states that there is no a statistically significant difference in achievement in chromatography and problem-solving skills between learners taught using PBL and those taught using structured inquiry-based science education method.

4.3 The impact of Problem-based Learning on learners' achievement and Problem-solving Skills.

In order to assess the impact of PBL on learners' academic achievement and Problem-solving skills, a paired T-Test was conducted to compare pre-test and post-test results for the experimental group. Results are in Table 4.3.

Table 4.3: Paired sample T-Test to compare pre-test and post-results for the experimental group.

Groups	Test	N	Mean	SD	df	T-value	P-value
Experimental	Pre-test	41	10.29	5.524	40	-34.202	.000
Experimental	Post-test	41	62.00	10.583			

Table 4.3 shows the pre-test and post-test mean scores of the experimental group as 10.29 (*SD* = 5.524) and 62.00 (*SD* = 10.583) respectively. The table further shows the t-value for 40 degrees of freedom as -34.202 and p - *value as* .00. The p-value is less than the critical value (0.05). Hence, there is a statistically significant difference between the pre-test mean score and the post-test mean score of the experimental group. This showed that Problem Based Learning had a positive impact on learners' achievement and problem-solving skills and therefore, we reject the null hypothesis which states that Problem-based learning has no impact on learners' achievement in chromatography and problem-solving skills.

4.4 The Impact of Problem-based Learning on Science Learning Activation

The following criteria was used to determine the extent of activation; a mean score of 3.50 to 4.00 = high science activation, 3.00 to 3.49 = moderate science activation, 2.00 to 2.99 = low science activation and 1.00 to 1.99 = no science activation.

Table 4.4 below shows the summary of pre-test and post-test results for Science Learning Activation for all sections of the Science Learning Activation Instrument.

Table 4.4: Science Learning Activation results analysis summary

SN	DIMENSION	Experimental Group		Control Group	
		Pre-test	Post-test	Pre-test	Post-test
		Extent of Activation	Extent of Activation	Extent of Activation	Extent of Activation
01	Fascination in Science	Low	High	Moderate	High
02	Values in Science	Low	Moderate	Low	Moderate
03	Competency Beliefs	Low	Moderate	Low	Moderate
04	Science Identity	Low	Moderate	Low	Low
05	STEM Career preference	Low	Moderate	Low	Low
06	Scientific Sense Making	Low	Low	Low	Low

Table 4.40 shows that learners in the experimental group exhibited moderate activation in values in science, competency beliefs, science identity and STEM career preference. The table further indicates that learners in the experimental group exhibited high and low activation in Fascination in science and scientific sense making

respectively. From the analysis above it can be concluded that the overall score for Science Learning Activation is moderate for the experimental group.

On the other hand, Table 4.40 indicates that learners in the control group exhibited high activation in fascination and moderate activation in values in science and competency beliefs. Learners exhibited low activation in science identity, STEM career preference and scientific sense making.

4.5: The relationship between achievement and Science Learning Activation

Table 4.5 shows the dimensions of Science Learning Activation, the extent of activation and the achievement mean score.

Table 4.5: Science Learning Activation, Extent of activation and achievement mean score

S N	Dimension	Extent of Activation	Achievement mean score	Overall Activation
01	Fascination in Science	High	62%	Moderate
02	Values in Science	Moderate		
03	Competency Beliefs	Moderate		
04	Science Identity	Moderate		
05	STEM Career preference	Moderate		
06	Scientific Sense Making	Low		

The achievement mean score for the experimental group was 62% and it was falling in the moderate range. Table 4.36 shows that learners were moderately activated and the achievement mean score (62%) was moderate. This means that there was a very strong positive correlation between achievement and Science learning Activation.

V. DISCUSSION, RECOMMENDATIONS AND CONCLUSION

Discussion

Impact of Problem-based learning on learners' academic achievement and problem-solving skills

The results show a significant difference in the achievement between the learners' achievement in the post- test after they were taught through problem-based Learning and Structured Inquiry-Based Science Education. Learners in the experimental group performed better than those in the control group. The difference in achievement mean scores for the experimental group between pre-test and post results was 51.71% which was higher than that of the control group which was 24.16%. This shows that the method used in the experimental group had more positive impact on learners' academic achievement. The results of this study are similar to those of Tarhan and Acar-Sesen (2013) and Uce and Ates(2016). These studies revealed that the mean scores of the learners in the experimental groups were significantly higher than those in the control groups and means that Problem-based learning increases learners' academic achievement in chemistry.

In the control group, the difference between pre-test and post mean scores was 24.16% which showed a significant difference and indicated that structured inquiry-based science education had a positive impact on learners' academic achievement but not as much as problem-based learning had.

Analysis of how learners performed on each item in the Chromatography and problem- solving skills test showed that learners in the experimental group showed great improvement in problem-solving skills. Both the experimental and control groups did not do well in problem-solving skills in the pre-test however, after the intervention, the experimental group did very well than the control group. As high as 82.9%, 75.6% and 70.7% of learners managed to give correct responses to questions 13. I (a) to 13.IV (c). This means that results show that a very good number of learners from the experimental group had developed the following problem-solving skills; understanding/identifying the problem, planning, implementing the plan of action and reflection. However, it should be noted that development of problem-solving skills is a continuous process and requires exposure to teaching approaches like problem-based learning several times.

Science learning activation

The analysis of data collected on the impact of Problem-based learning on Science learning activation show that Problem-based learning had a positive impact on Science Learning Activation. The analysis was done section by section and pre-test results were compared to post-test results.

Fascination in Science

Results of this dimension of Science learning Activation showed that learners improved from low activation in pre-test to high activation in both the experimental and control groups. This means that learners became highly fascinated after the intervention and that the intervention had a positive impact on learners' fascination in science. Fascination has the ability to capture and hold learners' attention and interest.

Values in Science

Post-test results showed that learners improved from low activation in Values in Science to moderate activation in both groups. Learners' values in science increased after exposure to problem-based learning and structured inquiry science education. This means that learners were able to appreciate and see the importance of chemistry in their daily lives after undergoing Problem-based learning. The two problem scenarios presented in this paper during the intervention were highly linked to what learners experience in communities where they come from and after seeing how useful Chromatography is in solving real-life problems, learners began to value chemistry. Problems presented in Problem-based learning provide learners with opportunities to apply the knowledge learned in class and this helps them to see and experience the usefulness of the chemistry content. According Lambros (2004) learners taught through problem-based learning benefit by becoming excited about resolving a given problem and discovering new information that helps in figuring out what is going on in the problem.

Competency Beliefs in Science

Results show that learners improved in Competency beliefs from low activation in pre-test to moderate activation in post-test in both groups. In Problem-based learning, learners benefit from working in small groups which are usually composed of learners with different levels of ability. High achieving learners help low achieving learners as a result low achieving learners develop higher competency beliefs (Bachman and O'Malley, 1986). Having positive beliefs is very important because when a learner believes that he/she is likely to be successful in solving a chemistry problem, then he\she will be more motivated to engage in academic activities to complete a task.

Science Identity

In this Science Learning Activation dimension, learners in the experimental group exhibited low activation in pre-test and moderate activation in post-test while those in the control group exhibited low activation even after being taught with structured inquiry science education. This is an indication that problem-based learning had a more positive impact on Science Identity. Research has shown that problem-based learning provides an environment in which learners become highly engaged with content and this arouses the interest of learners in science such that they even begin to identify themselves as science persons. Simulating real-world problems in class gives a sense of reality and therefore engages and motivates learners of all ages to like chemistry (UNESCO, 2012).

STEM Career Preferences

Results showed that learners in experimental group who indicated that they knew what kind of job they would want when they grow up improved from 66% to 93% while the control group improved from 57% to 94%. On this aspect, the control group did better by 1%. The overall activation of learners after the intervention in the experimental group in STEM career preferences dimension was moderate while the control group remained in low activation. This indicated that problem-based learning had more positive impact on learners than structured inquiry science education had. Authentic problems presented in Problem-based learning reflect real-world complexities and allow learners to explore specialisations as they research and solve real-world problems. This makes learners develop interest in STEM related careers as the see and experience how useful science is in their lives and communities were they come from. The overall activation for this section was moderate.

Scientific Sense Making

Learner in both the experimental and control groups showed low activation in this dimension of Science Learning Activation. Comparing pre-test results to post-test results, Learners showed little improvement but the improvement was not enough to move them from low to moderate or high activation. According to Dorph et al (2016), the activated science learner engages in scientific Sensemaking and he/she is able to ask good questions, seeks mechanistic explanations for natural and physical phenomena, engage in argumentation about scientific ideas, interprets data tables, designing investigations, and understands the changing nature of science. It should be noted that developing activated science learners requires effective science instructions and that it cannot be done within three weeks of teaching but it is a continuous process.

The analysis of Science Learning Activation indicated that learners in the experimental group were more activated than the control group.

Results from this study have shown that achievement is positively related to Science Learning Activation. The achievement mean score for the experimental group was 62% which falls in the moderate range and correlates positively with Science Learning Activation.

Implications of the Study

The vision of Zambia's education is to have a quality, life-long education for all which is accessible, inclusive and relevant to individual, national and global needs and value systems. In order to achieve this vision, Zambia's science curriculum was revised in line with outcome based principles which seek to link what is taught in schools to what learners experience in communities where they come from. This approach to education brings real-world situations in a chemistry class. The current study revealed that problem-based learning approach was found to help learners understand the concepts of chromatography and develop problem-solving skills through working on real-life problems.

Learners learn how to find and integrate information from different information sources provided by the teacher (who takes up the facilitator) as they go through an inquiry process. Information collected by learners helps them to understand the problem and eventually solve it. The use of real-world problems as a starting point for learning in problem-based learning approach allows learners to practice problem-solving skills such as understanding/identifying a problem, coming up with a plan of action, implementing a pan of action and reflection. Open ended problems presented to learners in a problem-based class give them an opportunity to go through an inquiry process as scientists do; they collect data from experiments, analyse it and interpret their results. Problem-based learning makes learning relevant to real-world by dealing with dealing with real-life problems and it brings an awareness of the connection between chemistry and society by presenting the importance of applying concepts from chemistry to explain and solve problems (Uyeda et al, 2002).

Solving real-world problems increases fascination in science and also makes learners begin to value what they learn as they realise that what they learn has real-world applications. This builds interest in learners and they begin to envision themselves pursuing STEM related careers. Therefore, it is suggested that teachers of chemistry should integrate problem-based learning in chemistry lessons by presenting ill-structured problems to learners. Problems are key to having an engaging lesson, therefore, teachers should make sure that problems are open ended and should reflect real-world situations. In addition, teachers should be trained about the implementation of problem-based learning and should know their role in a PBL class. Teachers should encourage learners to work collaboratively with fellow learners in small groups, compose driving questions and explanations to test their hypothesis about problems as scientists do.

Conclusion

The results of the study have provided evidence that Problem-based Learning if well implemented can have a positive impact on learners' academic achievement, foster the development of problem-solving skills and activate learners scientifically. The results have also shown that there is a positive correlation between achievement and Science Learning

Recommendations

The study makes the following recommendations; Since the study covered a small area and a small sample, the researcher recommends that additional research should be conducted which will involve more schools and a wider area to see if the same results can be obtained. This research should also be carried out in other topics to see if the same results can be realized. A research survey should be conducted at the secondary level which to examine the extent to which teachers make use problem-based learning. Finally, Chemistry teachers should be encouraged to adopt the use of problem-based learning technique at all levels of learning.

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