The Effects of Problem-Based Learning on Students' Cognitive Achievements in Some Selected Topics in Chemistry.

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ABSTRACT

This paper provides clear insight into the Effects of Problem-Based Learning on students' cognitive achievement in selected chemistry topics. The research design employed for the study was a Quasi-Experimental, specifically a non-equivalent control group pre–test–post–test design. The total population considered for the study consisted of two hundred and fifty (250) second-year senior high school students who learn chemistry as an elective subject in Nkrankwanta Senior High Technical School. The sample size was Eighty-five (85) elective chemistry students in Nkrankwanta Senior High Technical School. Two intact classrooms were used for the study. The control group consisted of forty-five (45) second-year students, and the experimental group consisted of forty (40) second-year students. The study employed a Chemistry Achievement Test (CAT) as the instrument. Initial assessments were administered to both groups, followed by a PBL intervention for the experimental group, and then post-tests for both groups. Data analysis incorporated percentages, descriptive statistics (mean and standard deviation), as well as inferential statistics (independent and paired samples t-tests). The findings revealed a statistically significant disparity in post-test scores between the control group (traditional teaching method) and the experimental group (PBL). Nevertheless, there was no significant difference in cognitive achievements between male and female students within the experimental group. The study therefore recommends the need for inclusion of the problem-based learning approach in the Senior High School chemistry syllabus and textbooks, as this can result in significantly higher students' cognitive achievement in chemistry concepts than the conventional approaches (traditional learning approaches).

Keywords: Problem-Based Learning; Cognitive Achievements; selected topics; chemistry

INTRODUCTION

Students' performance in chemistry depends on many factors and is a good indicator of how well students are doing. Teaching methods become an important pathway that should not be undermined by chemistry teachers and should be applied appropriately to enhance learning outcomes of students. In recent decades, there has been a shift in science education towards more student-centered teaching approaches. Dewey (1923) believed the world was constantly changing and students needed to be active learners engaged in the learning process.

According to Barron and Darling-Hammond (2008), students learn at deeper levels and perform better on complex tasks by engaging in authentic projects that draw subject knowledge to solve real-world problems. Indeed, relevant literature has shown that when students are involved in the learning process actively, meaningful learning, understanding, and retention can be enhanced (Ausubel, 1963).

For meaningful learning to take place, however, students should not acquire isolated facts; they should construct new knowledge by drawing relationships among several different concepts, both new and old(Hiebert & Carpenter, 2006). Therefore, it should be noted that regardless of which instructional approach is employed in the classroom, students' prior knowledge has a great influence on their further learning. Entwistle and Ramsden (1983) reported that students who adopt a meaningful learning approach are likely to find the task more interesting and easier to understand. In general, a meaningful approach is found to be associated with a deep level of understanding. In contrast, the rote approach to learning science involves both rote memorisation and syllabus-boundness. In this approach, the student intends to meet the minimum course requirements, and their external motive is to avoid failure by simple recall (Araz, 2007). A rote approach to learning is not sufficient to achieve a sound understanding of scientific concepts (Cavallo et al., 2004). It is widely acknowledged that chemistry is one of the most difficult subjects in secondary science as it contains aspects of chemical reactions that need to be understood to solve chemistry-related problems (Abdullah et al., 2013). Students' interest in chemistry continues to dwindle, not because schools lack professional chemistry teachers alone, but because the teaching approaches or methods used by teachers in teaching chemistry are also a factor to be considered. Several factors have been identified as the objectives of science instruction, but the most common factor documented by researchers is inappropriate and uninspiring teaching methods adopted in the teaching and learning of science (chemistry). The conventional method of teaching refers to teaching using chalk and board for teachers, pen and paper for students (Nnorom, 2008). The teacher-centred method does not promote skill acquisition, objectivity, and critical thinking ability among learners. There is a need for more activity-oriented, student-centred and innovative methods that can develop the students' science process skills, which include the problem-based learning method. The problem-based learning approach is a student-centred method where the teacher and students play an equal active role in the teaching and learning process. The teachers' primary role is to coach and facilitate student learning and overall comprehension of material while the students construct new ideas and concepts based on their past knowledge. To solve chemistry problems acceptably, the problem solver must have both conceptual scientific and procedural knowledge (Festus & Ekpete, 2012).

In the quest to pursue deeper learning for students, problem-based learning has emerged as a comprehensive approach to classroom teaching and learning that is designed to engage students in the investigation of authentic problems (Blumenfeld et al, 1991; McGrath, 2004; & MaKinster et al., 2001).

Objectives of the Study

The objectives of the study were to:

1. Investigate the extent to which the use of Problem-based learning will enhance students' achievement in chemistry.
2. Ascertain the differential impact of the problem-based learning approach on male and female students' cognitive achievement in the selected topics in chemistry.

Research Questions

1. What will be the extent of student's achievement in chemistry when exposed to the problem-based learning approach?
2. What is the differential impact of the problem-based learning approach on male and female students' cognitive achievement in the selected topics in chemistry?

LITERATURE

Theoretical Framework

Understanding how students acquire, create, and apply knowledge in educational environments is based on learning theories. They provide a variety of viewpoints on the teaching and learning process and guide the choice of instructional strategies that enhance academic performance and foster meaningful learning. Constructivism is one of the learning theories that has garnered the most attention due to its focus on collaborative learning, knowledge building, and active learner participation(Bada & Olusegun, 2015). Because they offer a solid theoretical foundation for the problem-based learning (PBL) strategy used in this study, constructivist learning theory, more specifically the ideas of radical and social constructivism, is the foundation of this research. As an alternative to behaviourism, which views learning as a behavioural shift brought about by reinforcement and outside stimuli, constructivism, on the other hand, sees education as an active cognitive process in which students build new knowledge by fusing fresh experiences with what they already know (Ausubel, 1963; Brown, 2006). According to this viewpoint, genuine learning happens when students actively participate in inquiry, introspection, and problem-solving as opposed to merely taking in knowledge from the instructor.

Radical constructivism holds that teachers serve as facilitators by directing students via suitable learning experiences, scaffolding, and questioning, while students actively generate knowledge through real-world learning experiences (Kauchak & Eggen, 1993; Fosnot, 2013).

According to social constructivism, students can build deeper conceptual knowledge and a common understanding through contact, collaboration, and discussion with teachers and peers (Derry, 1996)(Derry, 1996; McMahon, 1997; Wertsch, 1997). Additionally, it has been demonstrated that collaborative talks enhance students' critical thinking, reasoning, motivation, problem-solving skills, and conceptual knowledge (Corden, 2001; Jaworski, 2007). The problem-based learning approach, which involves students working together to investigate real-world problems, come up with answers, and build scientific understanding via inquiry, aligns with the ideas of radical and social constructivism. (Akcay, 2009).

Problem-Based Learning in the Senior High School Chemistry Education

Chemistry instruction necessitates the development of conceptual understanding, scientific reasoning, and the capacity to apply information in practical contexts(Jamil et al., 2024).

Conventional teacher-centered methods frequently place a strong emphasis on fact memorisation and replication, giving students few chances to participate in inquiry, critical thinking, and problem-solving(Stephan, 2020). As a result, learner-centred strategies like Problem-Based Learning (PBL), which actively involve students in creating knowledge through relevant learning experiences, are promoted in modern science education(Sebatana, 2020).

In problem-based learning, students investigate real-world, complicated issues that call for analysis, teamwork, information collecting, and the creation of potential solutions(Kwan, 2009). Problem-based learning gives students difficult scenarios that motivate them to come up with explanations, assess the evidence, and use scientific ideas to solve problems (Jonassen, 2011). According to Ertmer and Glazewski (2015), a key feature of problem-based learning is the transformation of classroom roles. Teachers act as facilitators, offering direction and scaffolding throughout the learning process, while students become active participants who take charge of identifying learning needs, gathering information, working with peers, and reflecting on their understanding (Dolmans et.al, 2016) Self-directed learning, communication skills, and higher-order thinking abilities, all crucial characteristics in contemporary science education, are fostered in this learner-centered setting

Research has indicated that Problem-based learning can improve students' academic performance, motivation, and problem-solving skills in chemistry education.(Aidoo et al., 2016; Arsyad et al., 2024; Benjamin, 2024; Günter & Alpat, 2017; Raman et al., 2024). Students are inspired to participate in scientific research and make significant connections between chemical principles and their environment through group projects and real-world issue scenarios.

Problem-based learning offers a viable substitute for the traditional method of teaching chemistry in senior high schools by giving students the chance to investigate chemical ideas via inquiry and real-world problem-solving exercises. It is pertinent for enhancing students' conceptual comprehension and equipping them with the scientific abilities needed in the twenty-first century because of its emphasis on active involvement, teamwork, and knowledge application.

METHODOLOGY

This study employed a quasi-experimental design, specifically the non-equivalent control group design with the intention of establishing a causal relationship between the control and the experimental group. In the study, two groups were selected using a convenience sampling technique, namely the experimental and control groups. The total sample size was Eighty-Five (85) elective chemistry students. This comprised Form Two Science One and Form Two Agricultural Science One students at Nkrankwanta Senior High Technical School. They were categorized as Control and Experimental groups. The Control group was made up of forty-five (45) students and the Experimental group of forty (40) students.

Since the study was carried out in a realistic classroom setting where it was impractical to randomly assign individual pupils, the use of a single senior high school and intact classes was deemed appropriate. Both groups completed a pre-test before the intervention and received instruction on the chemistry topics acids, bases, and salts, and redox reactions. Over the course of six weeks, the intervention was carried out during the regular chemistry class periods. The researcher used a structured problem-based learning (PBL) strategy to teach students in the experimental group about acids, bases, and redox reactions. Every lesson began with the presentation of a real-world chemistry problem intended to encourage investigation and group discussion. Under the teacher's direction, who mostly acted as a facilitator, students worked in small groups to identify the issue, propose potential explanations, collect relevant data, hold discussions, and suggest evidence-based remedies. The instructor monitored group dynamics, asked insightful questions as needed, and ensured that students actively developed their own conceptual understanding throughout the intervention. The regular chemistry teacher taught the control group using the conventional teacher-centred approach

To guarantee adherence to the desired teaching style, the researcher examined the lesson plans and observed classroom instruction during the study. Before the intervention, the control group teacher received orientation on applying the conventional instructional method.

Both groups took the Chemistry Achievement Test (CAT) as a pre-test at the start of the study, and students' performance was evaluated using the same test in an equivalent post-test version following the six-week intervention. A marking scheme created by the researcher was used to grade the completed exams.

Treatment of the Groups

Experimental Group

The study began with the administration of the pre-test to students in the experimental group. The pre-test administration took place with the help of the chemistry teacher in the selected senior high school for the study. The completed scripts were marked by the researcher using a marking scheme (scoring rubric) prepared by the researcher (Appendix C). The experimental group received the treatment (a problem-based learning approach).

The researcher used six weeks for the experimental process, during which the researcher handled the experimental group. The main treatment was teaching acids and bases and redox reactions to the experimental group using the lesson package problem-based learning approach developed by the researcher. All the necessary information about the concept were given and explained to the students. The students in the experimental group were guided to construct new ideas and concepts that are their own knowledge during and after the lesson, with the teacher acting as a facilitator by asking students probing questions that will enable them be on track, monitoring the process, and making resources available.

The teaching of the experimental group was done during the normal school's chemistry periods. The six-week experimental teaching process ended with the post-treatment Appendix

(B) consisting of twenty multiple-choice questions and one standard theory question different from the pre-test was given to the participants in the experimental group. The completed scripts were marked by the researcher using a marking scheme (scoring rubric) prepared by the researcher. Marking schemes for the pre-test (See Appendix C) and marking scheme for the post-test (See Appendix D).

Control Group

A pre-test was administered to participants in the control group. The pre-test administration took place with the help of the chemistry teacher in the selected senior high school for the study. The control group was taught using a conventional approach for the six weeks during which the experimental group was taken through a treatment procedure using a Problem-based learning approach. The researcher did not handle the control group because he wanted to prevent bias by the students in the control and the experimental group and also wanted to ensure independence among the students in both the control and the experimental groups. Also, since the study took place in an environment where the researcher was present, he monitored the teaching method adopted by the chemistry teacher in the control group and made sure he always uses conventional method, which involved the use of talk and chalk method on board style, in which the teacher dominates the teaching and learning encounter. The teaching of the control group was done during the normal school chemistry periods. The control group was taken through a conventional teaching approach for six weeks, after which a post-test was administered to the participants in the group.

Validity and Reliability

An instrument is considered valid when there is confidence that it measures what it is intended to measure in a given situation (Punch, 2013). The Chemistry Achievement Test (CAT) underwent extensive validity and reliability assessments to ensure that it measured students' achievement accurately and consistently.

The content validity of test items was determined by ensuring that questions for both the pre-test and the post-test were set from the selected topics used for the research and were within the scope of the Ghana Education Service-approved chemistry syllabus for Senior High Schools to ensure a fair and representative sample of questions. To ensure that participants' scores from the pre- test and post-test were valid and meaningful, and to ensure good conclusions from the sample studied and the research population, both test instruments were presented to four experts in chemistry education and four senior high school chemistry teachers for scrutiny. The study used a test-retest reliability method to assess the test items for both the pre-test and the post-test. In order to determine the reliability of the CAT, the instrument was pilot-tested among elective chemistry students at Mansen Senior High School in Wamfie, Dormaa East Constituency, whose characteristics were similar to those of the participants in the main study. The responses from the pilot study were subjected to item analysis, which included looking at item difficulty and discrimination indices to make sure the test items had acceptable measurement characteristics. Additionally, a test-retest reliability procedure was used, where the instrument was given to the same group of students three times over the course of three weeks. The scores obtained across the three administrations showed only negligible differences, indicating that the instrument produced stable and consistent results over time.

Cronbach's alpha coefficient was used to further assess the CAT's internal consistency, yielding a reliability coefficient of 0.80. According to Mugenda and Mugenda (2003) adequate internal consistency is indicated by a reliability coefficient of 0.70 or above. Consequently, the calculated coefficient showed that the Chemistry Achievement Test was appropriate for assessing students' academic performance in the topic and had sufficient reliability.

Data Analysis Procedure

The data obtained from the research participants through the pre-intervention and post-intervention tests were organised and summarised to obtain a general sense of information and to reflect on its overall meaning from the conducted research. The description and themes obtained were represented in quantitative terms and in qualitative narratives (e.g., frequency tables showing means, standard deviations, test statistics, and graphs). The researcher then made interpretations of the collected data based on literature findings and theories. Microsoft Excel and the IBM SPSS 26 software were used to assist and enhance the analysis. The researchers used a quantitative approach of data analysis for research question one (1), where they sought to determine the extent of students' performance in chemistry when exposed to the problem-based learning approach.

With this, the researchers conducted a pre-test and post-test with the experimental and control groups. The researchers adopted descriptive analysis of a quantitative approach, which sought to organize and describe the data by investigating how the scores on different constructs are related to each other. Furthermore, the pre-test and post-test scores were further analysed using an inferential approach for quantitative data analysis, where the researcher used a t- test statistic to determine if the treatment had effects on the groups. In this method of analysis, data obtained from participants in both experimental and control groups were analysed statistically using independent and dependent sample t-tests. The difference between the mean scores of both groups on the pre-test and post-test scores was tested at a 0.05 significance level.

The independent and dependent sample t-test was used to investigate whether any differences existed between experimental and control groups' mean scores on the chemistry achievement test (CAT).

Research question two (2), which sought to find the differential impact of the problem-based learning approach

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on male and female students' cognitive achievement in the selected topics in chemistry, also adopted descriptive and inferential statistics. The descriptive statistics, which employed the mean, helped in determining the relationship between the male and female students' scores in the experimental group in the pre-test and post-test. Pre-test and post-test scores were further analysed using inferential statistics for quantitative data, where the researchers used t-test statistics to determine if the treatment had any differential impact on the performance of male and female students exposed to the problem-based learning approach.

The difference between the mean scores of both groups on the pre-test and post-test scores was tested at a 0.05 significance level. The independent and dependent sample t-test was used to investigate whether any differences existed between the experimental group male and female students' mean scores on the Chemistry Achievement Test (CAT). This was done to answer the research question two 2.

FINDINGS AND DISCUSSION

Research Question 1

1. Investigate the extent to which the use of Problem-based learning will enhance students' achievement in chemistry.

Table 1.1: Independent Samples T-test of Pre-test scores of Chemistry Achievement Test (CAT)

Group	N	Df	Mean	SD	t- Value	P- Value
Control	45		21.29	3.709		
		83			11.920	1.143
Experimental	40		12.62	2.880		

Table 1.2: Dependent T- test of Pre-test and Post-test Scores of the Experimental Group Chemistry Achievement Test (CAT)

Group		N	DF	Mean	SD	t- value	P-value
	Pre –Test			12.62	2.880		
Experimental		40	39			-14.997	8.787E-18
	Post –Test			22.50	3.464		

Table 1.3: Independent T-test for Control and Experimental Post-test Scores of Chemistry Achievement Test (CAT)

GROUP	N	DF	Mean	SD	t-value	P-value
Control	45	83	11.82	3.786		
					-13.506	1.172E-22
Experimental	40		22.50	3.464		

DISCUSSION OF RESULT

To determine the extent to which the students in the experimental group performed when they were exposed to the problem-based learning approach, data on students' achievement test in pre-test and post-test were analysed using independent and dependent t-test statistics. As to whether PBL significantly influenced the experimental group performance in chemistry, data from the pre-test and post-test were analyzed using students' t-test, at $p < 0.05$. From Table 1.1, the mean score for the control and experimental group pre-test scores was 21.29 and 12.62, respectively.

The t-value from the computed t-statistics was 11.920 with a p-value of 1.143. The results of the pre-test showed that there was no significant difference between the experimental group and the control group, which affirmed that the performance of the groups was similar in solving chemistry problems. From Table 1.2, the computed data analysis revealed that the mean pre-test and post-test scores for the experimental group were 12.62 and 22.50,

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respectively. The mean difference between the pre-test and post-test scores of the experimental group was 9.88 which indicated a gradation in performance of the experimental group in solving chemistry problems. Also, the t-test results for the difference of means in the experimental group pre-test and post-test was -14.997 which was considered to be significant at the $p < 0.05$ level. This indicated that the experimental group performance in chemistry on the post-test was significantly better than their performance in. the pre-test. It was assumed that PBL is a speed bump for sparking this massive improvement in the performance of the students in the experimental group.

From Table 1.3, the computed data analysis on the post-test scores of the control and experimental groups revealed that the mean for the control and experimental post-test scores were 11.82 and 22.50, respectively. The mean difference between the post-test scores of the control and experimental group was 10.68, which indicated a complete difference in the performance of the experimental group from the pre-test. Also, the t-test results for the difference of means in the control and experimental group post-test were -13.506, which was considered to be significant at the $p < 0.05$ level. This therefore indicated that there was a significant difference in the performance of the control and experimental group post-test scores. This means that PBL intervention helped to improve the experimental group's performance in solving chemistry problems.

The higher mean of Students' responses to the post-test showed that students in the experimental group had significantly fewer alternative conceptions and understood the concepts more meaningfully than the control group (Tarhan & Acar, 2007). Since there was a significant difference in the performance of the experimental group exposed to PBL and the control group exposed to the conventional approach, it can be concluded that PBL is one of the innovative approaches to enhance teaching and learning in senior high school chemistry lessons. This helps to produce learners who are independent in their knowledge.

This is in support of the study conducted by Aidoo, Boateng & Ofori (2016) on the effect of problem-based learning on students' achievement in chemistry, which saw a significant difference between the students in the control group exposed to the traditional method and the students in the experimental group exposed to the problem-based learning approach. PBL enhances students' achievement by promoting their skills and capabilities in applying knowledge, by challenging students to solve problems, by encouraging them to practice higher-order thinking skills, and by directing their own learning (Jonassen et al., 2008). This lends credence to the fact that the adoption of a problem–based learning approach is a strategy which the science teacher can employ to improve the performance of students and their cognitive achievements in chemistry. These findings confirm earlier results obtained by Hussain and Anwar (2017)which revealed that the 10th grade students treated by the problem-based learning approach were significantly better in the achievement test in chemistry than the students treated by traditional methods.

Research Question 2

What is the differential impact of the problem-based learning approach on male and female students' cognitive achievement in the selected topics in chemistry?

This research question sought to determine the real impact of the problem-based learning approach on the cognitive achievement of male and female students' in the experimental group. An independent t-test was conducted on the male and female students' scores in the pre-test and post-test; this is represented in Table 1.4 and 1.5, respectively

Table 1.4: Independent T-test for Male and Female Students in the Experimental Group

Experimental Group	N	DF	Mean	SD	t- value	P- value
Males	24		12.79	2.587		
		38			0.8055	0.4255
Females	16		12.06	3.108		

Table 1.5: Independent Samples T-test for Post -Test Scores in the Experimental Group

Experimental Group	N	DF	Mean	SD	t- value	P- value
Male	24		22.33	3.371		
		38			-0.368	0.714
Female	16		22.75	3.697		

DISCUSSION OF RESULT

From Table 4.4, the computed p-value of 0.4244 was greater than 0.05, indicating that there was no statistically significant difference between the mean chemistry achievement pre-test scores of the male and female students in the experimental group. Also, it could be inferred from Table 1.5 that the computed p-value 0.714 was greater than 0.05 i.e., ($p > 0.05$), indicating that there was no statistically significant difference between the mean chemistry achievement post-test scores of male and female students in the experimental group. As a mean of determining the differential impact of the problem-based learning approach on the cognitive achievement of male and female students in the experimental group, an independent t-test at $p < 0.05$ was conducted to establish the differential impact of problem-based learning on the male and female students' pre-test and post-test scores. From Table 1.4, the mean score for the males and females in the experimental group pre-test scores was 12.79 and 12.06, respectively. The t-value from the computed t-statistics was 0.8055 with a p-value of 0.45255. This means that $p>0.05$, which indicated no significant difference in the performance of male and female students in the experimental group. This insinuated that the performance of male and female students in the experimental group was similar in solving chemistry problems. On the other hand, the post-test scores were also analysed statistically using an independent t-test to determine the differential impact of PBL on the male and female students in the experimental group. From Table 1.5, the mean scores for the males and females in the experimental group were 22.33 and 22.75, respectively. The t-value from the computed t-statistics was -0.368 with a p-value of 0.714.

This means that $p>0.05$. It was then concluded that there was no significant difference in the performance of male and female students in the experimental group post-test scores. The achievement scores of males and females can be attributed to the changing socio-cultural environment, which has widened the scope for equal educational opportunities for both males and females. Problem-based learning has a positive impact on the performance of the student irrespective of whether they are male or female. Problem-based learning has the potential to provide a conducive learning environment for the learner which promotes metacognition and self-regulated learning among learners, whether male or female. Since problem-based learning helps students acquire problem-solving skills which encourage lifelong self-learning, Students' exposed to PBL have the opportunity to work with authentic problems through several steps used to solve ill-structured problems.

The assumption is that when students solve problems like those encountered in real life, they are likely to improve their ability to solve various types of problems. Many studies have been conducted in an attempt to determine the differential impact of PBL on gender performance in chemistry. For instance, a study conducted by Etiubon and Ugwu (2016) indicated that there is no significant difference between the mean achievement scores of male and female chemistry students taught the concept of thermodynamics using the PBL approach. Also, a study conducted by Jimoh and Fatokun (2020) on the effect of PBL on chemistry students' achievement and interest in the mole concept indicated that gender has no significant effect on students' exposure to PBL since both male and female students had achieved equally. The findings from the empirical studies cited above indicated that the use of the problem-based learning approach promotes students' achievement in chemistry irrespective of their sex.

CONCLUSIONS

This study was about the effects of the problem-based learning approach on students' cognitive achievement in some selected topics in chemistry.

Firstly, the results of the study imply that students exposed to the PBL approach in teaching and learning of chemistry saw greater cognitive achievement in solving and understanding chemistry concepts than students exposed to the conventional approach. This was based on the premise of the higher mean of students' post-test scores in the experimental group than the control group post-test scores. It was therefore concluded that students exposed to the problem-based learning approach perform better in solving chemistry problems than students exposed to the conventional approach.

Secondly, the analysis of the mean chemistry achievement test scores of male and female students in the experimental group pointed out that the use of the PBL approach in teaching chemistry has no differential effect on students' achievement in chemistry, whether male or female. This conclusion was made based on the fact that no significant difference existed between the mean chemistry achievement pre-test and post-test scores of male and female students in the experimental group exposed to the problem-based learning approach. It was then concluded that problem-based learning has no discriminatory factor on the sex of the student. It is therefore suitable for improving the cognitive achievement of both male and female students.

LIMITATIONS AND FUTURE RECOMMENDATIONS

The results of this study demonstrate that problem-based learning improves students' cognitive achievement in chemistry, although they should be understood in light of significant constraints. First, two complete classes of 85 students were used in the study, which was carried out in a single senior high school. As a result, the results might not be easily applied to all Ghanaian senior high school pupils or to other educational settings. Additionally, the convenience sample and lack of random assignment may have limited the sample's representativeness; however, the study's internal validity was strengthened by several measures, such as the administration of a pre-test, equal instructional time, standardized assessment procedures, and ongoing monitoring of the intervention

Larger and more varied samples from several senior high schools in various parts of Ghana should be used in further research to replicate this study. Such a method would enable comparisons across various school kinds and learning environments while enhancing the findings' external validity and generalisability. To further lessen selection bias and support causal conclusions about the efficacy of problem-based learning, researchers should, whenever possible, also use random assignment or more stringent quasi-experimental techniques, such as matching or statistical controls such as analysis of covariance. Future studies may also look at how problem-based learning affects students' attitudes toward chemistry, scientific reasoning, problem-solving abilities, and retention of knowledge over time.

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APPENDICES

APPENDIX A

PRE-TEST

STUDENT'S ID

SECTION I

TIME ALLOWED: 40 MINUTES

From items 1 to 20, each item is followed by four options lettered A to D. Read each statement carefully and circle the letter that corresponds to the correct or best options.

1. Acids taste …..
   a. Sweet b. bitter
   c. Sour d. Salty
2. Bases react with
   a. Acids to produce salts and water b. water produces acids and salts
   c. Neither acids, salts nor water. d. Both acid and salt
3. Acids make litmus paper turn
   a. red b. yellow
   c. blue d. dry
4. Which type of solution is one with $_{P}H$ of 8
   a. Acidic b. conjugate
   c. neutral d. basic
5. An electron –pair acceptor is a
   a. Bronsted-Lowry b. Lewis acid
   c. Arrhenius base d. Lewis base
6. What is the $_{P}H$ of 1×10^{-5}
   a. 3 b. 5
   c. 9 d. 11
7. What is the correct products for these reactants HCl + NaOH $\rightarrow$
   a. HOH + ClNa b. SCl + H_2O
   c. H_3O^+ + $NaCl_2$ d. NaCl + H_2O
8. Strong bases are
   a. Strong electrolyte b. weak electrolyte
   c. nonelectrolyte d. also strong acids
9. A solution with $_{P}H$ of 5.0M
   a. Is basic b. has a hydrogen-ion concentration of 5.0M
   c. Is neutral d. has a hydroxide-ion concentration of 1

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10. Which ion do bases contain?

a. OH^- b. H_3O

c. H^+ d. NH_4^+

11. If an acidified solution of potassium Dichromate (VI) ($K_2Cr_2O_7$), Dichromate ion ($Cr_2O_7^{-2}$) becomes reduced to :

a. Chromate (v) ions b. Chromium (III) ions

c. Chromium (II) ions d. Chromium (V) ions

12. Which of the following is involved in oxidation?

a. loss of hydrogen b. loss of oxygen

c. gain in hydrogen d. gain in electrons

13. The total of the oxidation number is an element's

a. Volality b. charge

c. reduction d. Oxidation

14. The reduction is a gain of

a. neutrons b. Protons

C. electrons d. oxygen

15. Which of the following is not an example of redox reaction?

a. $CUO + H_2 \rightarrow Cu + H2O$ b. $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

c. $2K + F2 \rightarrow 2KF$ d. $BaCl_2 + H_2SO_4 \rightarrow BaSO_4 + 2HCl$

16. the oxidation number of phosphorus in the species HPO_3^{2-} is

a. +4 b. +5

c. +3 d. +2

17. Identify the correct statement (s) in relation to the following reaction:

$Zn + 2HCl \rightarrow ZnCl_2 + H_2$

a. Zinc is acting as an oxidant b. Chlorine is acting as a reductant

C. zinc is acting as an oxidant d. hydrogen ion is acting as an oxidant

18. $Sn^{4+} \rightarrow Sn^{2+}$ represents

a. Oxidation b. reduction

c. hydrolysis d. none of the above

19. In any oxidation-reduction reaction, the total number of electrons gained is

a. Unrelated to the total number of electrons lost equal
b. less than the total number of electrons lost
c. greater than the total number of electrons lost
d. equal the total number of electrons lost

20. Which of the following is a redox reaction?

a. $2KBr + F_2 \rightarrow 2KF + Br_2$
b. $2HCl + Mg(OH)_2 \rightarrow 2HOH + MgCl_2$
c. $2NaCl + H_2SO_4 \rightarrow Na_2SO_4 + 2HCl$
d. $Ca(OH)_2 + Pb(NO_3)_2 \rightarrow Ca(NO3)_2 + Pb(OH)_2$

APPENDIX B

POST -TEST

STUDENT'S ID

SECTION I

TIME ALLOWED: 40 MINUTES

From items 1 to 20, each item is followed by four options lettered A to D. Read each statement carefully and circle the letter that corresponds to the correct or best option.

1. Why is sulfuric acid (H_2SO_4) considered a Brønsted-Lowry acid?

a. It has a pH greater than 7 b. It is able to donate protons

c. It contains an hydroxide ion d. it reacts with hydronium ions

2. The compound Mg(OH)2 is classified as an Arrhenius base because, when the compound dissolves in water, there is an increase in the concentration of which of the following ions?

a. Hydrogen ions b. magnesium ions

C. hydroxonium ions d. oxide ions

3. The process in which acids (H^+) and bases (OH^-) react to form salts water is called

a. neutralization b. hydrogenation

c. halogenation d. sublimation

4. Which of the following compounds could produce hydroxonium ions in water?

a. calcium hydroxide b. hydrogen chloride

c. potassium chloride d. Sodium hydroxide

5. The concentration of the hydroxonium ion in a solution with pOH of 9 is

a. 10^{-5} mol dm^{-3} b. 10^{-7} mol dm^{-3}

c. 10^{-9} mol dm^{-3} d. 10^{-14} mol dm^{-3}

6. A substance which produces the hydroxonium ion as the only positive ion when dissolved in water is

a. an acid b. a base

c. an acid salt d. salt

7. Water is neutral because

a. the concentration of H^+ in water is greater than OH^-

b. the concentration of H^+ in water is equal to that of OH^-

c. the concentration of H^+ in water is less than that of OH^-

d. the concentration of H^+ per dm^3 of water constant

8. An aqueous solution of Na_2CO_3 is

a. alkaline b. acidic

c. amphoteric d. neutral

9. A substance responsible for the sour taste of unripe oranges is

a. alcohol b. alkanoic acid

c. alkanoate d. alkene

10. Weak bases

a. dissociates partially b. ionize completely

c. hydrolyze partially d. oxidize completely

11. The oxidation number of chlorine in in $KClO_3$ is

a. -5 b. -1

c. +1 d. +5

12. Which of the following is **not** oxidizing agent?

a. $KMnO_4$ b. MnO_2

c. O_2 d. H_2S

13. Consider the following redox reaction, what is the value of X ?

$$3Mg + xCr^{3+} \rightarrow 3 Mg^{2+} + xCr$$

a. 2 b. 3

c. 4 d. 6

14. Potassium is a stronger reducing agent than sodium because potassium

a. has higher atomic number b. has higher electron affinity

c**.** donates electron more readily d. has greater atomic radius

15. Consider the equation below:

$$Cr_2O_7{}^{2-} + 14H^+ + \square \rightarrow 2Cr^{3+} + 7 H_2O$$

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How many electrons must replace the box in order to balance the equation?

a. $2e^-$ b. $6e^-$

c. $8e^-$ d. $12e^-$

16. A redox equation is said to be balanced if

a. protons are added to the oxidant

b. electrons are added to the reductant

c. charges and atoms are balanced

d. molecules and neutral atoms are balanced

17. Which of the following reaction is a redox reaction?

a. $Cu_{(s)} + 4HNO_{3\,(g)} \rightarrow Cu\,(NO_3)_{2\,(g)} + 2NO_{2\,(g)} + 2H_2O_{(l)}$

b. $H_2SO_{4\,(aq)} + CuO_{(s)} \rightarrow CuSO_{4\,(aq)} + H_2O_{(l)}$

c. $H_2SO_{4\,(aq)} + 2NaOH \rightarrow 2Na_2SO_{4(aq)} + 2H_2O_{\,(l)}$

d. $FeCl_{3(aq)} + 3NaOH \rightarrow Fe(OH)_{3\,(aq)} + 3NaCl_{\,(aq)}$

18. Which element is reduced in the reaction?

$5Fe^{2+} + MnO_4^- + 8H^+ \rightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$?

a. hydrogen b. iron

c. manganese d. oxygen

19. An oxidizing agent

a. gains electrons b. loses electron

c. accepts oxygen c. increases its oxidation number

20. Which of the following processes is reduction?

a. loss of electrons b. gain electrons

c. gain of electron d. loss of hydrogen

SECTION II

Q1

(i) Classify each of the following as acidic or basic based on the information provided.

a) Lemon juice tastes sour

…………………………………………………………

b) A dilute solution of potassium hydroxide feels slippery

………………………………………………………….

c) Drain cleaner has a pH of 12

……………………………………………….

d) an aqueous solution Na_2CO_3 of pH 11

…………………………………………………….

Q1.

(ii) Consider the following redox equation

$$Fe^{2+}{}_{(aq)} + Cr_2O_7^{2-}{}_{(aq)} + H^+{}_{(aq)} \rightarrow Cr^{3+}{}_{(aq)} + Fe^{3+}{}_{(aq)} + H_2O$$

Write the half ionic equation for the

(α) oxidation reaction

……………………………………………………………………………………………

……………………………………………………………………………………………

(β) reduction reaction

……………………………………………………………………………………………

…………………………………………………………………………………………….

(δ) Write a balanced ionic equation for the overall reaction

………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………