A Comparison between Chemistry Students' Mathematics Knowledge and Achievement in Basic Thermodynamic Concepts Using Inquiry Instruction

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Abstract

This study examined the comparison of the chemistry students' mathematics knowledge and achievement in basic thermodynamic concepts in inquiry instruction. The research design for the study was quasi-experimental of pre-test post-test design to determine the relationship and difference between chemistry students' mathematics knowledge and achievement. One hundred and nine chemistry students in senior secondary school form two (SS2) were randomly sampled from six public schools in a local government area in Oyo State, Nigeria. The research instruments were an instructional package for engaging the students in inquiry instruction, the mathematics knowledge test, and the achievement test of thermodynamic concepts. The validated instruments were test-retested to determine their reliabilities. The instruments had high positive correlation coefficients of 0.89 for the mathematics knowledge test and 0.87 for the achievement test in thermodynamic concepts. The instruments were pre-administered to the students before engaging the students in active learning for six weeks in thermodynamic concepts and were post-administered after the treatment. The chemistry teachers in the sampled schools were trained on the instructional package to facilitate the students' learning. The students' responses to the research instruments were analysed using paired samples correlation and paired sample t-test to compare and find the difference between the students' mathematics knowledge and achievement in thermodynamic concepts in chemistry in the pre-test and post-test. The results showed a positive relationship between pre-test and post-test mathematics knowledge and achievement. There was a significant relationship between post-mathematics knowledge and post-achievement in thermodynamic concepts. Also, there were significant differences between pre-test and post-test mathematics knowledge and achievement in thermodynamics. The study recommended adequate knowledge of mathematics and inquiry instruction to learn chemistry concepts effectively.

Keywords: Inquiry instruction, mathematics knowledge, achievement, thermodynamic concepts, chemistry.

Introduction

Mathematics deals with the shapes, arrangement and quantity of objects. The basic measurements in mathematics, are length, time, mass and volume. The derivations of all measurements in science including chemistry, are from these basic measurements. Chemistry is all about matter, which is about everything in the universe, the compositions, properties and the transformations that accomplish matter. Chemistry and mathematics are interrelated and inseparable from one another. Both chemistry and mathematics are part of everything that human beings do.

Yau (2019) identified some of the concepts in mathematics that are in relation to chemistry as exponents, scientific notation, orders of operation, algebra, unit conversion, and dimensional analysis. Apart from the mentioned, modelling is more of a mathematics concept and is used in the physical modelling of atoms to represent molecules and some other processes like chemical bonding, hybridization of orbital and in electron tunnelling in chemistry. Specifically, mathematics signs and symbols like negative sign (-), positive sign (+) and delta Δ are used to show the number of electrons loss, gain and changes that occur during the transformation of matter, respectively. Logarithm is used in the determination of hydrogen ion concentration $[H^+]$ in a solution. Ratio and proportionality are used in the mixing of solution, dilution and analysis of molecular structures and in the determination of moles of matter, to mention but few.

The finding of Kanwal et al. (2022) on the effect of conceptual understanding of mathematical principles and academic achievement of secondary level chemistry students showed that there was a significant difference between conceptual understanding of mathematical principles and chemistry achievement of the students.

Jantur (2022) found a significant relationship using Pearson Product Moment Correlation between the students' performances in chemistry and mathematics in senior secondary school certificate examination. Anchen and Ying (2022) results showed that there was a strong positive linear relationship between students' mathematics and chemistry learning. The study suggested that good mathematics knowledge can improve students' achievement scores in chemistry. The study of Ayeni (2022) et al. also indicated that a positive correlation between students' performance in mathematics and chemistry among senior secondary school students in Oyo East Local Government of Oyo State. Charles-Ogan et al. (2017) findings on the effects of mathematics knowledge on chemistry students' academic performance in gas law showed a significant difference between the performance of mathematics high and low in chemistry.

Gordon (2022) observed that mathematics is being widely used in chemistry. Mathematics is used in the exploration of some concepts in chemistry and without some basic mathematics skills, calculations in chemistry as well as understanding of chemistry concepts would be difficult. Iwuanyanwu (2021) found that the common deficiencies of mathematics skills among chemistry students are lack of skills in algebra, curve sketching, simple differentiation and integration caused students to struggle in understanding chemistry concepts. The students lacked ability to solve complex relations of mathematics concepts in chemistry problems. The students' inability to process information and lacked adequate ability to represent number and pattern and visual spatial concepts in mathematics.

The learning of chemical thermodynamic concepts, involves energy transformations with chemical reaction or with physical changes of states of matter. The thermodynamic concepts are quantitative and qualitative in nature. The effectiveness of teaching and learning of thermodynamic concepts require basic knowledge of mathematics.

The cognitive constructivists were of the views that learning should be active, and complex process of constructing knowledge from learning environment and acquired from the environment rather than being told facts and principles by the teachers. (Dewey, 1949; Bruner, 1967; Ausubel, 1968 and Piaget, 1983). Constructivist theories of learning foster the development of critical thinking skills through analysis of information, evaluation of evidence, consideration of multiple perceptions of information and solving complex problems. These processes are to promote cognitive flexibility where learners can apply the knowledge acquired to solve problems in new situations. These would lead to meaningful learning and deepening student knowledge of the contents rather than memorisation if properly implemented in the classroom. In a similar vein, social constructivists believed that knowledge is a human product that is socially and culturally constructed from experience (Vygotsky, 1978). According to Vygotsky (1978), knowledge is not individually constructed but co-constructed among people. Vygotsky's Zone of Proximal Development (ZPD) was used to refer to the difference between what learners can do and what they can do with the assistance of others.

Learning in inquiry is a multifaceted process of active engagement of students in task work, exploration, investigation, experimentation, discussion and problem-solving. It is a student-centred approach that encourages curiosity, critical thinking, and problem-solving skills. The goal of inquiry instruction is to foster a deeper understanding of concepts and to develop the ability to independently acquire and apply knowledge These processes based on modern learning theories which emphasised constructions of knowledge from learning experiences (Piaget, Bruner and Ausubel) and from social interactions with peers (Vygotsky). The inquiry instructions had been found to promote skills acquisition, understanding of conceptual knowledge, computational knowledge, creativity and logical reasoning in chemistry (Adeoye, 2016). The findings also indicated that students' mathematical ability had significant effect on computation knowledge of Senior Secondary School Two students in chemistry.

STATEMENT OF THE PROBLEM

Students' failure in chemistry had been linked to their performance in mathematics as reported by West African Examination Council, WAEC, Chief Examiner's report in the subject as candidates have once again failed to make use of basic principles of mathematics in a simple calculation. Teachers have important roles to play here in establishing their students' confidence in the area of chemical arithmetic (WAEC, 2021, pp. 12) Several studies have shown relationships and differences between mathematics knowledge and performance in chemistry. Most of these studies were centred on the chemistry students' perceptions. Akinoso et al. (2016) showed that chemistry students perceived knowledge of mathematics as related to the students' knowledge of mathematics. However, limited studies exist on the comparison of students' mathematics knowledge and chemistry performance in basic thermodynamic concepts in chemistry. Adeoye (2023) found a significant difference in the chemistry students' achievement when structured inquiry-based instruction was used to strengthen the students' knowledge in basic thermodynamic but the influence of mathematics knowledge on the students' achievement was not examined.

The study investigated the relationship between students' mathematical knowledge and students' achievement in thermodynamics and the difference between students' mathematics knowledge and achievement in basic thermodynamic concepts using an inquiry mode of instruction.

RESEARCH HYPOTHESES

The formulated null hypotheses at 0.05 level of significance for the study are:

Ho_1 There is no significant relationship between pre-mathematics knowledge and pre-achievement of thermodynamic concepts in chemistry.

Ho_2 There is no significant relationship between post-mathematics knowledge and post-achievement of thermodynamic concepts in chemistry.

Ho_3 There is no significant difference between pre-mathematics knowledge and pre-achievement of thermodynamic concepts in chemistry.

Ho_4 There is no significant difference between post-mathematics knowledge and post-achievement of thermodynamic concepts in chemistry.

METHODOLOGY

The research design was a quasi-experimental of pre-test post-test design, to find the influence of inquiry instruction on students' mathematics knowledge and achievement of basic thermodynamic concepts. Specifically, to determine the relationship between students' mathematics knowledge and achievement and find if there was significant difference exist between the variables.

The population for the study was the senior secondary school students form two (SS2) in a Local Government Area of Oyo State. Six secondary schools were randomly selected for the study. The SS2 chemistry students in their intact classes in the randomly selected schools were the selected samples for the study. The chemistry teachers in the randomly sampled schools were trained on the structured inquiry instructions to facilitate the students in the learning of basic thermodynamic concepts after the students had been taught using traditional method. The thermodynamic concepts were both qualitative and quantitative in nature. The treatment was for six weeks of active learning of the concepts on forms of energy, energy conversions, endothermic, exothermic and enthalpy determination. The responses of one hundred and nine (109) chemistry students who actively participated in inquiry mode of instruction and did both mathematics knowledge test and achievement among the samples were analysed for the study. The instructional package activities were adapted from Ojokuku (2017). The samples of the activities and expected observations / explanations as shown:

Activity 1

Aim: To demonstrate energy changes that accompany physical and chemical processes (exothermic changes).

Materials: Sodium hydroxide (NaOH) pellets, potassium hydroxide (KOH) pellets, calcium (II) oxide, CaO, 2.0 moldm^{-3} of HCl, concentrated hydrochloric acid, concentrated tetraoxosulphate (VI), H_2SO_4, distilled water, test tube, boiling tube, thermometer, iron fillings, zinc metal.

Procedure:

a. Put about 10 cm^3 of distilled water in a test tube and take its initial reading temperature, T_1. Add 3 or 4 pellets of sodium hydroxide into the water, carefully stir the mixture with a thermometer, and then, record the highest temperature as T_2 of the mixture.
b. Repeat the experiment with KOH and CaO.
c. Repeat the experiment carefully by adding 2 cm^3 of concentrated HCl.
d. Repeat the experiment carefully by adding 2 cm^3 of concentrated H_2SO_4.
e. Repeat the experiment by put 15 cm^3 of 2.0 moldm^{-3} HCl into a boiling tube and take its initial temperature T_1. Add a spatula full of iron fillings or 3 granules of zinc metal. Stir the mixture carefully with a thermometer and record the highest temperature, T_2.

Observations and Explanations

In each of the experiment, the final temperature T_2 is greater than the initial temperature T_1. That is $T_2 > T_1$. There is a rise in the temperature of the mixture in each case. Hence the mixture becomes warm or hot. The temperature change, ΔT is positive, the processes are exothermic. That is, heat energy is given off by the reactants to the surrounding.

Activity 2

Aim: To illustrate energy changes that accompany physical and chemical processes (endothermic changes).

Materials: Ammonium chloride, NH_4Cl, ammonium trioxonitrate (V), NH_4NO_3, potassium trioxonitrate (V), KNO_3, sodium ethanoate, CH_3COONa, barium hydroxide, $Ba(OH)_2$, distilled water, test tube, boiling tube, thermometer.

Procedure:

a. Put about 10 cm^3 of distilled water in a test tube and take its initial temperature, T_1. Add a spatula full of ammonium chloride, NH_4Cl, crystals into the water. Stir the mixture carefully with a thermometer, and record the lowest temperature as T_2 of the mixture.

b. Repeat the experiment with: i. ammonium trioxonitrate (V), NH_4NO_3 ii. potassium trioxonitrate (V), KNO_3 iii. sodium ethanoate, CH_3COONa.

c. Put 10 cm^3 of distilled water in a test tube and take its initial temperature T_1. Place a spatula full each of crystals of barium hydroxide and ammonium chloride in a boiling tube, and add the water from the test tube into it. Stir the mixture with a thermometer, and record the lowest temperature, T_2 of the mixture.

Observations and Explanation

In each of the experiments, the final temperature T_2 is less than the initial temperature of the mixture, as a result, the mixture becomes cold. That is, $T_2 < T_1$ and the temperature change, $T_2 - T_1$, ΔT is negative. Therefore, these processes are endothermic, that is heat energy is absorbed by the reactants from the surroundings.

Activity 3

Aim: To determine the heat of solution of substances in water.

Materials: simple calorimeter or bomb calorimeter, ammonium chloride, NH_4Cl, sodium hydroxide (NaOH) pellets, thermometer, beaker.

Procedure:

a. Measure 50 cm^3 of distilled water into bomb calorimeter (or an insulated beaker by lagging) and record its temperature T_1. Add 10 pellets (1.0g) of NaOH into the water, stir the mixture carefully with a thermometer, and record the highest temperature T_2 of the mixture.

Assumption: The following assumptions should be made:

i. the mass of 1cm^3 of the solution is 1.0 g.

ii. the heat gained or lost by the plastic cup or insulated beaker is negligible.

iii. the specific heat capacity of the solution formed is 4.2 $Jg^{-1}K^{-1}$.

Note: Specific heat capacity is the heat required to raise 1 g of a substance by 1 k temperature.

b. Repeat the procedure for ammonium chloride, NH_4Cl

c. Determine the heat change and standard heat change for the dissolution of each of the substances.

d. Identify and explain the energy changes that accompanying each dissolution.

Explanation and Observations

Calculation from dissolution of NaOH in water from data obtained from an actual experiment:

Temperature T_1 of water = 27.0 ^{0}C = 300 K

Highest temperature T_2 of solution = 31.0 ^{0}C = 304 K

Change in Temperature = $T_2 - T_1$ = (304 - 300) ^{0}C = 4 K

Heat evolve = Total mass of solution x rise in temperature x specific heat capacity

= 50.0 g x 4.0 K x 4.2 J = 840.0 J

That is, 1.0 g of NaOH evolved 840.0 J

Molar mass of NaOH = 23 +16 +1 = 40 gmol^{-1}

40.0 g (1 mole) of NaOH evolved 840 x 40 J = 33600 J per mole = 33.6 kJmol^{-1}.

The dissolution of NaOH in water is exothermic because change in temperature is positive. That is, heat energy is liberated from the system to the surrounding. For the dissolution of ammonium chloride, NH_4Cl, is endothermic because temperature change is negative. Heat energy is absorbed from the surrounding to the system.

Note: The above procedure can be used to calculate heat change of the NH_4Cl if the experimental data are known. Molar mass of NH_4Cl = 14 + (1x4) +35.5 = 53.5 gmol^{-1}

RESEARCH INSTRUMENTS

There were two research instruments, the achievement test and mathematics knowledge test. The achievement is an essay type of test, that sought information on students understanding of the basic thermodynamic concepts. The test consisted of ten major questions that required reasons for their responses to each question. Samples of the questions are:

Samples of the Test Items on Thermodynamics Concepts

1a. In a thermodynamic reaction, what is the reaction conducted in a beaker or test tube called?

b. Give reason for your answer.

2a. What is an enthalpy change, ΔH that is recognised by a fall in the temperature of a system?

b. Give reason for your answer

3a. Will the heat liberated when 1.0 g of NaOH pellets dissolve in 20 cm^3 of distilled water be less or greater than when 2.0g of NaOH pellets dissolve in the 20 cm^3 of distilled water?

b. Give reason for your answer.

The mathematics knowledge test was a 20-item multiple choice questions with four options on algebra, simple percentage, proportionality etc that are useful in understanding and in solving quantitative questions in thermodynamic. Samples of the test are:

1. Simplify 10 $\frac{2}{5} - 6\frac{2}{3} + 3$

A $6\frac{4}{15}$ B $6\frac{11}{15}$ C $7\frac{4}{15}$ D $7\frac{11}{15}$

2. Reduce the fractions of $\frac{24}{30}$ to lowest

A $\frac{2}{3}$ B $\frac{3}{5}$ C $\frac{4}{5}$ D $\frac{2}{3}$

3. What is the value of the 3 in 0.438

A 4.3 hundredth B 3 thousandth C 3 unit D 4.3 tenth

Validation and Reliability of the Instruments

The research instruments were given to two veteran chemistry educators and two mathematics educators for content and construct validity. The validated instruments were then pilot tested using pre-test post-test method, in a school that was not part of the sampled schools for the study. The Pearson Product Moment reliability coefficients were of 0.87 for achievement and 0.89 for the mathematics knowledge test.

RESULTS

Table 1: ***Chemistry Students' Pre-Test and Post-Test Mean and Standard Deviation of Mathematics Knowledge and Achievement in Thermodynamic Concepts***

Test	Mean	N	Std. Deviation	Std. Error
Pre-test Achievement	7.51	109	1.39	.1333
Pre-test Mathematics Knowledge	7.14	109	1.06	.1014
Post-test Achievement	14.17	109	1.96	.1879
Post-test Mathematics Knowledge	10.28	109	1.13	.1082

Testing of Hypotheses

Ho_1 There is no significant relationship between pre-mathematics knowledge and pre-achievement of thermodynamic concepts in chemistry.

Ho_2 There is no significant relationship between post-mathematics knowledge and post-achievement of thermodynamic concepts in chemistry.

Table 2: ***Correlations of Pre-test Post-test Mathematics Knowledge and Achievement in Thermodynamic Concepts***

Pair	Test	N	Correlation	Sig.

Paired 1	Pre-test achievement in thermodynamics and pre-test mathematics knowledge	109	.153	.113
Paired 2	Post-test achievement in thermodynamics and post-test mathematics knowledge	109	.396	.000*

* Correlation is significant at 0.05 at $p \leq .05$

The variables paired 1 on Table 2 show a positive relationship between pre-test achievement in thermodynamics and pre-test mathematics knowledge, with a correlation value of .153. The variables paired 2 on Table 2 of post-test achievement in thermodynamics and post-test mathematics knowledge indicate a positive relationship between the variables, with a correlation value of .396.

The variables paired 1 on Table 2 also shows no significant relationship between pre-test mathematics knowledge and pre-test achievement of thermodynamic concepts since *p*-value > .05. The null hypothesis of no significant correlation between pre-test mathematics knowledge and pre-test achievement of thermodynamic concepts was therefore accepted. However, there was a significant relationship between post-test mathematics knowledge and post-test achievement of thermodynamic concepts since the p-value was less than .05 as indicated in Table 2 of variable paired 2. Hence, the null hypothesis which stated that there is no significant relationship between post-test mathematics knowledge and post-test achievement of thermodynamic concepts was rejected.

Testing Hypotheses

Ho_3 There is no significant difference between pre-mathematics knowledge and pre-achievement of thermodynamic concepts in chemistry.

Ho_4 There is no significant difference between post-mathematics knowledge and post-achievement of thermodynamic concepts in chemistry.

Table 3: ***Paired Samples T-Test of Pre-mathematics Knowledge-Pre-achievement and Post-mathematics Knowledge-Post- achievement***

Paired	Test	Mean	Std. Dev.	Std. Error	t -value	Df	Sig.
1	Pre-achievement & Pre-mathematics Knowledge	.376	1.615	.155	2.432	108	0.017*
2	Post-achievement & Post-mathematics Knowledge	3.899	1.836	.176	22.177	108	0.000*

* Paired samples t-test is significant at $p \leq .05$

The variables paired 1 in Table 3 shows a significant difference between the pre-mathematics knowledge and pre-achievement of thermodynamic concepts since *p*-value < .05. The null hypothesis, Ho_3 which stated that there is no significant difference between pre-mathematics knowledge and pre-achievement of thermodynamic concepts in chemistry was rejected. Hence, there is a significant relationship between pre-mathematics knowledge and pre-achievement of thermodynamic concepts in chemistry.

The variables paired 2 in Table 3 shows that there is significant difference between post-mathematics knowledge and post-achievement of thermodynamic concepts in chemistry since the p-value was less than 0.05. The null hypothesis Ho_4, which stated that there is no significant difference between post-mathematics knowledge and post-achievement of thermodynamic concepts in chemistry was rejected.

DISCUSSION OF THE FINDINGS

A positive and significant relationship exists between students' mathematics knowledge and achievement in chemistry show that mathematics knowledge has significant relationship with chemistry especially with thermodynamics. That is, the mathematics knowledge the students have, the greater would be the students' achievement in chemistry. Knowledge of mathematics significantly promote the students' achievement in both quantitative and qualitative in chemistry. This affirms that mathematics knowledge promotes the achievement of chemistry concepts as against the finding of Adeoye (2016) who found that students' mathematical ability only influences the students' knowledge of computational knowledge in chemistry. This finding also statistically affirms Akinoso et al. (2016) who found that chemistry students' perception that adequate knowledge of mathematics applied to chemistry influences the students' performance in chemistry. The finding of a significant relationship between mathematics knowledge and chemistry is also in support of the finding of Jantur (2022) who found significant relationships between the students' performances in chemistry and mathematics in the senior secondary certificate examination.

The study also found that there is a significant different in the mathematics knowledge and chemistry achievement in inquiry instruction. That is, the inquiry instruction had a significant effect on chemistry students' mathematics knowledge and achievement in thermodynamic concepts. This further explains that as the students' knowledge of mathematics increases, their achievement in chemistry also increases. This is in support of Adeoye (2023) that inquiry instruction strengthened the students' understanding of basic thermodynamic concepts.

CONCLUSION

In conclusion, mathematics knowledge is related to chemistry. Adequate knowledge of mathematics promotes understanding of chemistry and achievement in chemistry.

1. There is no significant relationship between pre-mathematics knowledge and pre-achievement of thermodynamic concepts in chemistry.

2. There is a significant relationship between post-mathematics knowledge and post-achievement of thermodynamic concepts in chemistry.

3. There is a significant difference between pre-mathematics knowledge and pre-achievement of thermodynamic concepts in chemistry.

4. There is a significant difference between post-mathematics knowledge and post-achievement of thermodynamic concepts in chemistry.

RECOMMENDATION

The following recommendations are made:

1. Secondary students should have at least a credit pass in mathematics to take a course in chemistry.

2. Chemistry students should acquire basic mathematics skills of unit conversions, algebra, mathematics notations for calculations and modeling chemistry concepts for proper understanding of chemistry.

3. Active teaching methods like inquiry instruction, if properly engaged in the classroom, have the potential to boost students’ mathematics knowledge and achievement in chemistry.

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