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Effects of Inquiry-Based Learning Strategies on Chemistry Students' Conceptions in Chemical Kinetics and Equilibrium

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ABSTRACT: The study identified Senior Secondary School II (SS2) students' misconceptions and determined the effect of inquiry-based learning strategies: Investigate Discuss (ID), Predict-Discuss-Investigate-Discuss (PDID) and Teacher Demonstration (TD) on students' conceptual knowledge at macroscopic, microscopic and symbolic levels in chemical kinetics and equilibrium. The pre-test post-test quasi experimental control group design as adopted. 359 SS2 chemistry students were randomly sampled from nine public schools in Lagos States, Nigeria. The validated Conceptual Knowledge Test (CKT) was easy test, structured to reflect the three levels of conceptual knowledge was the major instrument for the study. There were operational guides for the learning strategies which comprised eight practical activities that had same contents but different procedural steps in their implementations. The mean, simple percentage and bar chat were used in analysing students responses to pre-test and post-test of CKT. The study identified the students' misconceptions in chemical kinetics and equilibrium. The results indicated that the ID followed by the PDID was more effective in promoting conceptual knowledge of microscopic and symbolic levels in chemical kinetics and equilibrium. The ID and PDID learning strategies are recommended for chemistry teaching to improve students' achievement in conceptual knowledge at microscopic and symbolic levels of content representations in chemistry.
***KEYWORDS*:** Conceptual knowledge, learning difficulties, content representation levels, Predict - Discuss - Investigate - Discuss, Investigate - Discuss, Teacher Demonstration

I. INTRODUCTION

Chemistry should be learnt at three levels of content representations: macroscopic, microscopic and symbolic for meaningful understanding of the chemical concepts (Gilbert & Treagust, 2009; Adeoye, 2011 and Adesoji & Omilani (2012). The macroscopic level corresponds to knowledge acquired through observation of an object such as physical properties, change of states of matter, solubility and precipitation of solutes among others. The microscopic level uses the particulate nature of atoms to explain the concepts, principles and theories of the observable phenomena while the symbolic level involves the use of chemical symbols, formulae, reaction mechanism, chemical equations to represent phenomena at macroscopic and microscopic levels. It is pertinent that chemistry students at all levels of education have adequate knowledge of scientific concepts at the three levels and should be able to integrate the knowledge across the levels with ease (Gilbert & Treagust, 2009).

Research findings have shown that a huge gap existed between the intended chemistry curriculum and actual happenings when students learn chemistry. Students' inability to demonstrate good understanding of very basic concepts of the subject has been reported (Ali, 2012). The students' inadequacies in scientific concepts are refered to as misconceptions or alternative conceptions (Harizal, 2012). Several misconceptions have been identified in some topics in chemistry such as particulate nature of matter and chemical bonding (Othman, Treagust & Chandrasegaran, 2008), acid-base (Harizal, 2012), chemical thermodynamic (Sokrat, Tamani & Radid, 2014), periodicity (Satilmis, 2014) and redox reaction (Shehu, 2015). The commonly reported difficult chemistry topics in Nigeria context are redox reactions, electrolysis, chemical equilibrium, chemical kinetics, mole concepts and stoichiometry (WAEC, 2009-2013). Some of the identified reasons for students' misconceptions include: lack of deep conceptual knowledge; inability to integrate ideas to coherent conceptual framework; inability to represent the macroscopic to microscopic and symbolic concepts, inadequate basic mathematical knowledge and inadequate methods of the teaching (Kolomuc & Calik, 2012; Sokrat, Tamani & Radid, 2014 and Shehu, 2015). Misconceptions impede learning of new concepts which result into poor performance of students in chemistry (Taber, 2009 and Satilmis, 2014). Sakiyo & Badau (2015) indicated that the average performance of Nigeria students in chemistry who obtained grade 1-6 was 46.30 % in West African Senior School Certificate Examination (WASSCE) from 2008 - 2012.

It is necessary to identify and remediate students' misconceptions in chemical concepts through appropriate instructional strategies. Obviously, ordinary form of instruction such as lectures, laboratory activities, discovery learning or simply reading textbooks are not very successful at overcoming students' misconceptions in some chemistry topics (Burgoon, Heddle & Duran, 2010). Several instructional strategies have proven to be effective in achieving conceptual change and assist to learn correct concepts in science. Ozmen (2011) suggested computer animation for nature of matter and transformation, conceptual change oriented instruction through demonstrations for rate of reaction by Kaya & Geban (2012), Intervention Discussion Learning Model (IDLM) for chemical bonding by Ikenna (2015), inquiry-based/guided discovery teaching strategies (Adekunle, 2015 and Maxwell, Lambeth & Cox, 2015) and V-shape and conflict map learning strategies for chemical kinetics (Adeoye, 2017) . Students must be actively involved in learning by construction and reorganisation of their previous experiences. These would be more beneficiary for meaningful learning in chemistry (Ajeyalemi, 2011 and Adeoye, 2016).

The emphasis in the assessment of students' learning difficulty of chemistry concepts is currently based on students' achievement in macroscopic, microscopic and symbolic. However, there is limited studies on the effectiveness of learning strategies on the students achievement at the three levels of contents representations in chemistry especially in chemical kinetics and equilbrium.

II. PURPOSE OF THE STUDY

The purpose of the study was to determine students' achievement in chemical kinetics and chemical equilibrium and to identify some common students' misconceptions in the topics. The study also examined the effect of inquiry-based learning strategies on students' conceptual knowledge at the three levels of content representations. The specific objectives are to:

a. Determine study achievement in chemical kinetics and chemical equilibrium
b. Identify students' misconceptions in chemical kinetics and chemical equilibrium.
c. Examine the effect of inquiry-based learning strategies on students' conceptual knowledge in chemical kinetics and chemical equilibrium.
d. Determine the effect of inquiry-based learning strategies on students' conceptions at the three levels of content representation in chemical kinetics and chemical equilibrium.

III. RESEARCH QUESTIONS

a. How do the students achieve on chemical kinetics and chemical equilibrium before treatment?
b. What are the students' misconceptions in chemical kinetics and chemical equilibrium?
c. What are the effects of the inquiry-based learning strategies on students' conceptual knowledge in chemical kinetics and chemical equilibrium?
d. How do the inquiry-based learning strategies affect students' conceptions at the three levels of content representation in chemical kinetics and chemical equilibrium?

IV. METHODOLOGY

The quasi-experimental research design of pre-test and post-test experimental control groups were employed to determine the effect of three inquiry-based learning strategies on students' conceptual understanding.

Three hundred and fifty nine (359) senior secondary II (SS2) chemistry students were randomly sampled from nine public secondary schools in Lagos State, Nigeria. The schools were grouped into three designated treatment groups as Predict-Discuss-Investigate-Discuss (PDID), Investigate-Discuss (ID) and Teacher Demonstration (TD). The students in their intact classes randomly sampled, comprised 114 students for the ID treatment group, 123 students for the PDID while the TD group had 122 students. The PDID and ID were student-centred learning strategies while the TD was teacher-centred approach to teaching. All the sampled students in the three learning strategies were exposed to four weeks of practical activities in chemical kinetics and equilbrium. The procedures for implementing learning contents were different.The chemistry teachers in the sampled schools were trained on the learning statrategies as they were applicable to the schools. The learning strategies were based on the constructivism theories of learning of Dewey, Piaget, Bruner, Vygotsky and Ausubel which stressed that knowledge is constructed and co-constructed among knowledgeable peers from the environment. Trowbridge & Bybee (1990) and Kolb's (1988) experiential learning a four-stage cyclic model that involves concrete experience, reflective observation, abstract conceptualization and active experimentation using 5Es learning processes (Engage, Explore, Explain, Elaborate and Evaluate).

The students in the PDID and ID treatment groups learnt in small discussion group of 5 to 6 members in a group. The PDID students made predictions and discuss the predictions of experimental outcomes before carrying out the investigation. The results of the investigation were also discussed. The students modified their predictions as they discussed and carried out investigation.

The students in ID carried out investigations and discussed their findings with their peers without making predictions. In the TD, the teachers carried out the investigations without the assistance of the students. The teachers explained the underlying principles and theories of the practical activities. The trained teachers in the PDID and ID facilitated learning and modified students discussions where necessary while the teacher in TD acted as custodian of knowledge and the students, as passive learners.

V. RESEARCH INSTRUMENT

There were operational guides for the three learning strategies which contained eight practical activities structured to reflect the learning strategies 1 hour for each practical activity per week.

The Conceptual Knowledge Test (CKT) research instrument was structured by the researchers to determine the students' conceptual knowledge at macroscopic, microscopic and symbolic levels of content understanding on the chemistry topics. The CKT contained eight open-ended questions: two questions on each of the four chemistry topics, with three sub-questions. The CKT was validated and reliability coefficient value was 0.73. The instrument was pre-administered to the samples before treatment and post- administered two days after the treatment.

VI. ANSWERS TO RESEARCH QUESTIONS

The students' scores on pre-test post-test were analysed using mean and simple percentage to provide answers to the research questions raised for the study.

Research Question 3a: How do the students achieve on chemical kinetics and chemical equilibrium before treatment?

Based on the results presented on Table 1, the students' percentage score before treatment was 30.75 % of which the percentage score of the students were 15.81 % for chemical kinetics and chemical equilibrium had 14.94 %. The score indicated that students have learning difficulties in chemical kinetics and chemical equilibrium. The percentage score of the students after the treatment was 46.65 % out of which chemical kinetics had 23. 06 % while chemical equilibrium had 23.58 %. This showed an improvement in the students' scores. If inquiry-based learning strategies are to be used in engaging chemistry students in the topics for a long period of time, the learning strategies are capable of eliminating or alleviating students' learning difficulties in the areas of chemistry. The students' achievement by learning strategies was examined.

Table 1: Students Mean Achievement in Conceptual Knowledge Test by Topic

Treatment	Test	Mean Chemical Kinetics	Mean Chemical Equilibrium	Total Mean
	Pre-test	7.71	6.96	14.67
ID	Post-test	11.73	12.21	23.94
	Mean Gain	4.02	5.25	9.27
	Pre-test	8.32	5.80	14.12
PDID	Post-test	11.03	10.05	21.08
	Mean Gain	2.71	4.25	6.96
	Pre-test	6.76	8.74	15.50
TD	Post-test	10.45	11.70	22.15
	Mean Gain	3.69	2.96	6.65
	Pre-test	7.59	7.17	14.76
Average	Post-test	11.07	11.32	22.39
	Mean Gain	3.48	4.15	7.63

Source: Adeoye (2016)

Research Question 3b: What are the students' learning difficulties in chemical kinetics and chemical equilibrium?

The identified learning difficulties and the expected knowledge from the students in chemical kinetics and chemical equilibrium are as follows:

Chemical Kinetics

For chemical kinetics, the students found it difficult to:

- State two factors that determine whether or not the collision of two reacting particles would lead to formation of products.

(i) There must be effective collision because not all collisions lead to formation of products.

(ii) Energy of collision must be equal or greater than activated energy.

- Draw an energy profile for a catalysed exothermic reaction. Some of the students did not know that both catalysed and uncatalysed energy profile would be on the same diagram. Some drew the energy profile correctly but failed to label and indicate activated complex, activation energy and enthalpy change diagram.
- Concisely describe the effects on the rate of reaction when pressure of A is doubled in this reaction: $A_{(g)} + B_{(g)} \longrightarrow C_{(s)} + D_{(g)} \quad \triangle H = -210\ KJmol^{-1}$

When pressure of A is doubled, reactant particles collide more often if they are crowded in a small space i.e. frequency of collision is dependent upon pressure. An increase in pressure, results in a corresponding increase in effective collision of the particles of A and hence in the reaction rate.

Chemical Equilibrium

In chemical equilibrium, the students encountered difficulties in:-

- Identifying and writing chemical reaction for the ions that form an insoluble hydroxide with $NaOH_{(aq)}$ in the following chemical equilibrium mixture:

$$Fe^{3+}_{(aq)} + 3SCN^{-}_{(aq)} \rightleftharpoons Fe(SCN)_{3(aq)}$$

Fe^{3+} reacts with NaOH to form insoluble Fe $(OH)_3$ and the equation for the reaction is:

$$Fe^{3+}_{(aq)} + 3OH^{-} \longrightarrow Fe(OH)_3.$$

- Explaining what would happen if more KSCN were added to the equilibrium mixture.

Consequently, on adding more of KSCN(aq) to the equilibrium mixture, the red colour deepens because addition of KSCN increases the concentration of SCN^- causing equilibrium to shift to right.

- ❖ Stating what will happen if more heat is applied to this reaction:

$X_{2(g)} + 3Y_2 \longrightarrow 2XY_{3(g)} \qquad \triangle H = -92\ KJmol^{-1}$

The reaction will shift from right to left favouring the production of $X_2 + 3Y_{2\,(g)}$ (reactants)

- ❖ Writing equilibrium constant for this reaction:

$CaCO_{3(s)} \rightleftharpoons CaO_{(s)} + CO_{2\,(g)}$

Majority of the students expressed equilibrium constant as

$$K_c = \frac{[CaO][CO2]}{[CaCO3]}$$

The $CaCO_{3(s)}$ and $CaO_{(s)}$ are not the concentration of the substances. Concentration can only be expressed in solution.

- ❖ Explaining comprehensively the effects of increase pressure and temperature on equilibrium reaction using Le-Chatelier's Principle on this reaction:

$N_{2\,(g)} + 3H_{2\,(g)} \rightleftharpoons 2NH_{3\,(g)} \quad \triangle H = -92kJmol^{-1}$

Research Question 3c: What is the effect of the inquiry-based learning strategies on students' conceptual knowledge in chemical kinetics and chemical equilibrium?

From the results on Table 1, the mean gain of the students in the ID was 9.27 (40.52 %) while that of their counterparts in PDID and TD were 6.96 (30.42 %) and 6.65 (29.05 %) respectively in both chemical kinetics and chemical equilibrium. The pattern achievement in chemistry by learning strategies was ID > PDID > TD. By topic, the students' mean gain in the ID was 4.02, the PDID had 2.71 while the TD had 3.69 on chemical kinetics. For chemical equilibrium, the students mean gain in the ID was 5.25 while the students in the PDID and the TD were 4.25 and 2.96 respectively. The pattern of achievement was ID > TD > PDIP in chemical kinetics and ID > PDID > TD in chemical equilibrium. These results indicated that ID inquiry-based learning strategy was most effective for learning chemical kinetics and chemical equilibrium in chemistry.

Research Question 3d: How do the inquiry-based learning strategies affect students' conceptions at the three levels of content representation in chemical kinetics and chemical equilibrium?

The students' achievements in the three levels of contents in the topics by learning strategies groups are presented in Table 2.

From results on Table 2, the comparison of the mean gain scores on macroscopic, microscopic and symbolic levels of the three learning strategies by chemistry topic was made. The results indicated that the students in the TD group had the highest score on macroscopic level for chemical kinetics (2.32) and chemical equilibrium (1.52) than the ID and the PDID strategies. The students in the ID learning strategy had the highest mean gain score on microscopic level with 2.20 and 2.31 for chemical kinetics and chemical equilibrium respectively. The ID learning strategy was also most effective for symbolic level for chemical kinetics with highest mean gain of 1.37 and 2.04 for chemical equilibrium.

Table 2: Mean Scores at Macroscopic, Microscopic and Symbolic Levels in Chemical Kinetics and Chemical Equilibrium

Learning Strategy	Level of Representation	Chemical Kinetics Mean of Pre-test	Post-test	Gain	Chemical Equilibrium Mean of Pre-test	Post-test	Gain
ID	Macroscopic	2.74	3.19	0.45	2.32	3.22	0.90
	Microscopic	2.62	4.82	2.20	2.26	4.57	2.31
	Symbolic	2.35	3.72	1.37	2.38	4.42	2.04
	Total Mean	11.73	7.71	4.02	6.96	12.21	5.25
PDID	Macroscopic	2.68	3.42	0.74	1.86	3.07	1.21
	Microscopic	3.06	4.64	1.58	1.82	3.56	1.74
	Symbolic	2.58	2.97	0.39	2.12	3.42	1.30
	Total Mean	8.32	11.03	2.71	5.80	10.05	4.25
TD	Macroscopic	2.24	4.56	2.32	2.36	3.88	1.52
	Microscopic	2.32	3.20	0.88	2.84	3.96	1.12
	Symbolic	2.20	2.69	0.49	3.54	3.86	0.32
	Total Mean	6.76	10.45	3.69	8.74	11.70	2.96

Bar chart was also used to represent students mean gain scores in the learning groups on levels of content representations. The students mean gain scores on the three levels of conceptual knowledge by the learning strategies on chemical kinetics and chemical equilibrium are pictorially represented and shown on Figure 1 for better understanding of the findings.

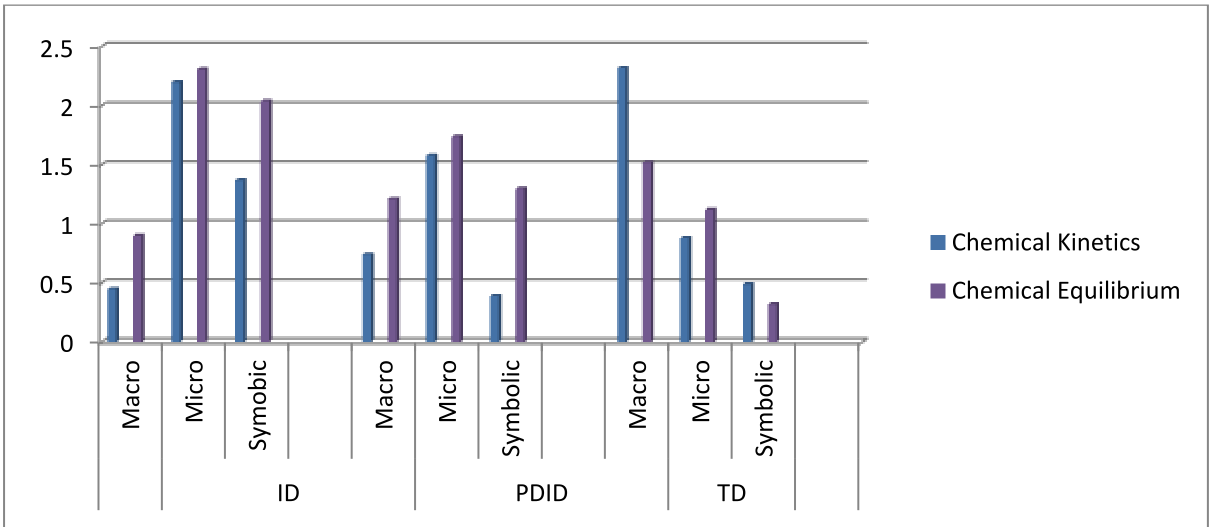

Figure 1: Representation of Students' Mean Gain at Macroscopic, Microscopic and Symbolic Levels by Topic

The Figure 1 indicated that the ID was most effective for microscopic and symbolic levels of conceptual knowledge for both chemical kinetics and chemical equilibrium. The TD strategy was most effective for macroscopic level in the two chemistry topics. The patterns of the students' achievement on the three levels content representations based on learning strategies for chemical kinetics topic are TD > PDID > ID for macroscopic level; microscopic level, ID > PDIP > TD; and symbolic level was TD > ID > PDID. For chemical equilibrium, the achievement patterns based on the learning strategies for macroscopic level was TD > PDID > ID and ID > PDID > TD for both microscopic and symbolic levels.

VII. DISCUSSION

The active involvement of the students in carrying out practical activities, the discussions of findings among themselves within a group and translations of what were observed during investigations to microscopic and symbolic levels as the students reported their findings may have enhanced their achievement in conceptual knowledge. The strategy encourages the students to express their ideas, opinions and reflect on the findings in open dialogue. The students' thoughts are clarified on the outcomes of their investigations as they dialogued among themselves which consequently led to high quality learning. This finding is in support of Abungu, Okere & Wachanga, 2014; Ehindero, Ojediran & Oludipe, 2014 and Adekunle, 2015 who found inquiry teaching effective in promoting achievement and Guevara (2015) that found co-operative teaching effective for enhancing academic achievement in science.

The Predict-Discuss-Investigate-Discuss being most effective than the Teacher Demonstration may be due to the fact that the teacher's role was shifted to the students which allowed for active participation of the students rather than being passive in the teaching and learning process. The act of students making predictions, discussing the predictions with members of the group, carried out investigations to see whether the predictions and discussions made were appropriate to the findings from the investigations and modifications of the predictions and discussions where necessary might have made the Predict-Discuss-Investigate-Discuss better strategy than the Teacher Demonstration. The students' misconceptions were modified after carrying out investigations. The findings also made the students to express and modify their own views through open dialogues and active participation hence, learning was enhanced. The observable concepts were translated to microscopic (molecular) and symbolic (structural) representations as the students discussed and reported their investigations. These assisted the students to improve their academic competence. This finding is in agreement with Ogunleye & Babajide (2010) and Sesen & Tarhan (2013) who found that the Predict-Observed-Explain teaching strategy enhances students' understanding of scientific concepts in secondary schools.

VIII. CONCLUSION

The study has shown that active learning promotes students' achievement of the macroscopic, microscopic and symbolic levels in chemistry. Chemistry teachers should provide enriching and challenging learning environment for students to explore for meaningful learning of scientific concepts. Chemistry students should be allowed to interact with one another and discuss the knowledge constructed from the environment to enhance their learning. Students pre-existing knowledge should be identified and appropriate instructions should be employed for remediation when their conceptions is not consistent with scientific knowledge. Active participation of students in teaching and learning processes promotes retention and learning of new concepts.

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