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Effects Of Inquiry-Based Learning Strategies, Gender And Mathematical Ability On Students' Skills Acquisition In Chemistry

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Abstract: ***The study examined the effects of inquiry-based learning strategies, gender and mathematical ability of senior secondary school form two chemistry students on acquisition of basic science and life coping skills. Three hundred and fifty nine (359) were randomly sampled from nine (9) secondary schools in Nigeria. The schools were randomly assigned to the inquiry-learning strategies of Investigate-Discuss (ID), Predict-Discuss-Investigate-Discuss (PDID) and Teacher Demonstration (TD). The pre-test post-test control group of quasi experimental research design was employed for the study. The chemistry teachers in the sampled schools were trained on the implementations of the learning packages as it was applicable to each school. The validated and reliable research instruments of Mathematical Ability Test (MAT) and Skills Acquisition Test were used to categorise the students into low, medium and high mathematical ability and to determine students' acquisition of skills. The results indicated that the students acquired higher skills in science basic skills than life coping skills. There is significant different in skills acquisition of the students based on learning strategies with the PDID > TD > ID. There is no significant main and interaction effect of students' gender and mathematical ability on skills acquisition. The recommendations are made based on the findings.***

Keywords: Inquiry learning, Mathematical ability, Gender, Science basic skills, Life coping skills.

I. INTRODUCTION

The 21st century skills are essential for learners to develop deep and effective learning in classroom. They are known as life coping skills which are capability that students need to survive and thrive in the world of works. These works are not readily available to everyone and even when available, an individual has to possess adequate knowledge and skills to compete for them. The skills are grouped into three namely learning skills, literacy skills and life skills. The learning skills are critical thinking, creative thinking, collaborating and communicating. The literacy skills are information literacy, media literacy, technology literacy while life skills are flexibility, initiative, social skills, productivity and leadership (Stauffer, 2020).

The emphasis of science learning should be based on developing these skills and enhancing meaningful understanding of content knowledge in active engagement of students in the learning process. Science instruction must address the nature of science and the practices of science. The practices of science are ways by which scientific knowledge and developed which are known as scientific processes or skills. Padilla (1990) and Ekon and Eni (2015) classified science skills into two major types: basic and integrated. The basic skills are observing, predicting, classifying, measuring, communicating and inferring. They are the foundation for learning science and acts of scientists. The integrated science process or skills are controlling variables, defining operations, formulating hypothesis, interpreting data, experimenting and formulating models.

In order to achieve the aims of learning science which stress meaningful understanding of concepts and skills acquisition, inquiry learning is adjudged one of the best teaching methods (Adeoye and Ajeyalemi, 2016; Jack, 2018; Adeoye, 2019). Inquiry is an activity-oriented learning that involves active engagement of students and problem-solving

in teaching and learning process. Deep knowledge is built and scientific skills are effectively acquired when students are active participants in teaching and learning process. However, the most common instructional method in science generally and particularly in chemistry in Nigeria schools is lecture method. This method is generally employed to cover all topics as stipulated by syllabus for examination. Teacher demonstration method is sometimes employed for quantitative analysis when external examinations are approaching. Consequently, Adeoye and Ajeyalemi (2018) Abbey-Kalio and Arokoyu (2019) and Adeoye (2019) found lecture and the teacher demonstration methods inadequate in promoting deep and effective knowledge of scientific concepts, students' interest and skills' acquisition in science. Gultepe (2016) examined the views of high school science teachers on science process skills. The study found that science process skills have a positive effect on science teaching and that in-class activities promote conceptual learning. The sampled teachers were of the opinions that skills are effectively acquired through laboratory activities that actively engage both teachers and students. The study further indicated that central examination-based teaching is great challenge to laboratory activities.

Amanso and Bassey (2017) study revealed that male students in science differ significantly from their female counterparts in acquisition of science process skills. The findings also showed that science students from public schools differ significantly from their counterparts in private schools in computation and making of inference skills. However, there was no significant difference in problem-solving skills between science students from private and public schools.

The study of Sesen and Tarhan (2013) on inquiry learning showed that it promotes students attitude, scientific creativity, skills acquisition and achievement in chemistry. Jack (2018) revealed that students' gender has negligible influence on students' acquisition of scientific process skills. However, large class size has great influence on students' science process skills. The study concluded that most Nigerian students experience difficulty in acquiring science process skills. This may probably be as a result of large class size and in proper structured of instruction in inquiry. Tosun (2019) determined that grade level, gender and mother's education level were variable that affect middle school students' scientific process skills levels. It was also showed that out-of-school opportunities like participation in science fairs, reading of scientific journals and designing science project have predictive effect on students' levels of scientific process skills acquisition.

Furthermore, Ogbeba and Ajayi (2018) found that students that were taught using hand-on activities did significantly higher in mean skills acquisition scores than those that were taught using discussion method of instruction. The study also indicated that male and female students were not significantly difference in their mean skills acquisition in hand-on activities. Omosewo (2016) also indicated that hands-on activities showed superiority results than other methods on students' performance in chemistry. Al-Mustapha (2014) found that there was no significant difference on students' acquisition of male and female in Basic Science. However, Abe (2011) found that gender disparity existed in students' skills acquisition in Biology. The female students significantly acquired skills higher than their female counterparts.

There are different approaches to inquiry-based learning. There is need to determine the effects of the approaches like Teacher Demonstration (TD), Investigate-Discuss (ID) and Predict-Discuss-Investigate-Discuss (PDID) on students' acquisition of science basic skills of observing, classifying, predicting, measuring and inferring and life coping skills such as critical thinking, collaboration, leadership, communication and accountability. The effect of students' factors; gender and mathematical ability and their interaction effects with the treatment would be examine on chemistry students skills acquisition.

II. PURPOSE OF THE STUDY

The study was to determine the achievement of senior secondary school chemistry students in acquisition of basic process and life coping skills. The effect of the inquiry-based learning strategies on skills acquisition was investigated. The study also examined the main effect of treatment, gender and mathematical ability and the interaction effect of these factors on students' skills acquisition.

RESEARCH QUESTIONS

The research questions raised for the study are:

- ✓ What are senior secondary school chemistry students' level of skills acquisition in basic process and life coping skills?
- ✓ What are effects of ID, PDID and TD inquiry-based learning strategies on senior secondary school chemistry students' skills acquisition?
- ✓ How does students' mathematical ability influence senior secondary school chemistry students' mean scores in skills' acquisition?
- ✓ What is the influence of gender on senior secondary school students' mean scores in skills' acquisition?

Research Hypotheses

The null research hypotheses that were formulated for the study are:

H_0^1 There is no significant main effect of treatment on senior secondary school chemistry students mean scores in skills' acquisition.

H_0^2 There is no significant effect of mathematical ability on senior secondary school chemistry students mean scores in skills' acquisition.

H_0^3 There is no significant effect of gender on senior secondary school chemistry students mean scores in skills' acquisition.

H_0^4 There is no significant interaction effect of treatment and mathematical ability on senior secondary school chemistry students in skills' acquisition. .

H_0^5 There is no significant interaction effect of treatment and gender ability on senior secondary school chemistry students in skills' acquisition.

H_0^6 There is no significant interaction effect of mathematical ability and gender on senior secondary school chemistry students in skills' acquisition.

H_0^7 There is no significant interaction effect of treatment, mathematical ability and gender on senior secondary school chemistry students in acquisition of life coping skills.

III. RESULT AND DISCUSSION

ANSWERING OF RESEARCH QUESTIONS

✓ What are senior secondary school chemistry students' level of skills acquisition in basic process and life coping skills?

Basic Process Skills:	Mean Post-test	Mean Pre-test	Mean Gain	21st Century Skills	Mean Post-test	Mean Pre-test	Mean Gain
Observing	6.37	4.48	1.89	Leadership	6.86	6.02	0.84
Classifying	5.72	4.13	1.59	Communication	5.70	4.45	1.25
Measuring	5.88	3.89	1.99	Collaboration	6.96	4.80	2.16
Inferring	4.96	3.31	1.65	Accountability	5.89	4.70	1.19
Predicting	5.40	4.68	0.72	Critical Thinking	5.09	3.28	1.81
Total	28.33	20.49	7.84		30.50	23.25	7.25

Source: Adeoye (2016)

Table 1: Acquisition of Basic Process and 21st Century Skills

The students' skills acquisition on basic process and 21st century skills was difference. The students' mean gain score for basic process skills was 7.84 while that of 21st century skills was 7.25 as presented on Table 1. These results indicate that, the treatments had slightly positive effect on basic process skills than 21st century skills.

The effect of treatment of the students with ID, PDID and TD indicated achievement mean gain pattern of measuring > observing > inferring > classifying > predicting in basic process skills. The pattern of the mean gain values in 21st century skills was collaboration > critical thinking > communication > accountability > leadership. The treatments enhanced more skills acquisition in basic process skills than 21st century skills. The treatments had least mean scores in predicting and leadership of basic process and 21st century skills respectively.

The mean gain scores of the students in basic process and 21st century skills as presented pictorially in Figure 1.

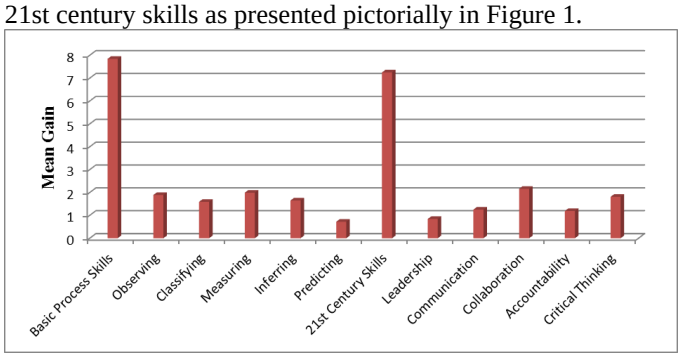

Figure 1: Students' Skills Acquisition in Basic Process and 21st Century Skills

✓ What are effects of ID, PDID and TD inquiry-based learning strategies on senior secondary school chemistry students' skills acquisition?

Treatment	N	Mean ($\bar{x}$) Pre-test ($\bar{x}$)	(SD)	Standard Deviation (SD) Post-test ($\bar{x}$)	(SD)	Mean Gain
ID	114	41.22	8.75	49.45	8.63	8.23
PDID	123	48.71	7.45	75.59	12.50	26.88
TD	122	41.30	8.41	51.46	9.16	10.16

Table 2: Pre-test and Post-test Mean Scores on SAT by Treatment

The students' mean gain scores in skills acquisition presented on Table 2 show that the students in the PDID group had the highest score of 26.88 in skills acquisition. The ID and TD groups' students had 8.23 and 10.16 respectively. The pattern of the effectiveness of the inquiry-learning strategies on skills acquisition was the PDID > TD > ID.

The results of further analysis on students post mean score and standard error are presented in Table 3.

Category		N	SAT Mean	SAT Std. Error
Treatment	ID	114	49.01	1.296
	PDID	123	76.83	1.638
	TD	122	50.75	1.440
Mathematical Ability	Low	92	61.31	1.370
	Medium	226	58.89	.715
	High	41	56.40	1.980
Gender	Male	214	58.99	1.003
	Female	145	58.74	1.340

Table 3: Students Mean and Standard Error Scores on Skills Acquisition Test by Treatment, Mathematical Ability and Gender

The pattern of students' skills acquisition on Table 3 also indicated PDID > TD > ID with the mean post scores of 76.83, 50.75 and 49.01, respectively.

✓ How does students' mathematical ability influence senior secondary school chemistry students' mean scores in skills' acquisition?

The students with low mathematical ability had the highest mean score of 61.31 followed by medium, 58.89 while the high mathematical ability had 56.40 in skills acquisition as presented in Table 3.

✓ What is the influence of gender on senior secondary school students' mean scores in skills' acquisition?

The results in Table 3 indicate that both male and female students had equal mean scores of 58.99 and 58.74, respectively in skills' acquisition.

These findings are further presented in Figure 2 which shows the statistic descriptions of treatment, mathematical ability and gender on acquisition of skills.

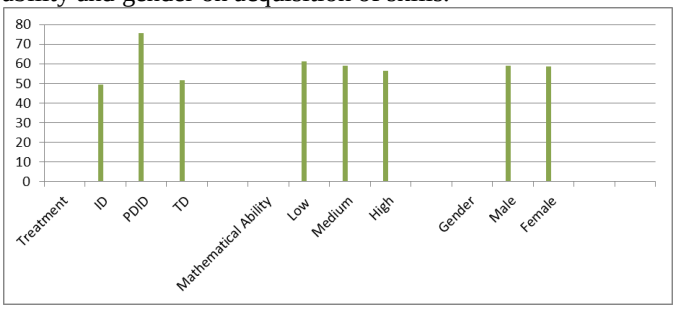

Figure 2: Graphical Representations of Treatment, Mathematical Ability and Gender on Skills Acquisition

Testing of Research Hypotheses

Research Hypothesis H_0^1 There is no significant main effect of treatment on senior secondary school chemistry students' mean scores in skills' acquisition.

Source	Type III Sum of Squares	Df	Mean Square	Partial Eta Squared	F	Sig.
Corrected Model	53228.293	18	2957.127	.600	28.366	.000
Intercept	36333.449	1	36333.449	.506	348.523	.000
PRESAT	47.241	1	47.241	.001	.453	.501
Treatment	21201.024	2	10600.52	.374	101.64	.000*
Gender	2.207	1	2.207	.000	.021	.884
Math. Ability	473.255	2	236.627	.013	2.270	.105
Treatment * Gender	532.902	2	266.451	.015	2.556	.079
Treatment * Math. Ability	217.016	4	54.254	.006	.520	.721
Gender * Math. Ability	139.244	2	69.622	.004	.668	.513
Treatment * Gender * Math. Ability	120.522	4	30.130	.003	.289	.885
Error	35444.894	340	104.250			
Total	1342722.000	359				
Corrected Total	88673.187	358				

*$R = .600$; $R^2 = .579$ * Significant at $p < .05$*

Source: Adeoye (2016)

Table 4: Summary of ANCOVA on Skills Acquisition by Treatment, Gender and Mathematical Ability

The results of the analysis indicate significant main effect of treatment on skills acquisition ($F_{(2,340)} = 6.273$; $p < .05$) as shown in Table 4. The null hypothesis H_0^1 is rejected. There is therefore significant difference in the mean scores of the senior secondary school chemistry students in skills' acquisition based on treatment.

(I) Treatment	N	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.
ID	114	PDID	-26.09	1.336	.000*
		TD	-1.96	1.339	.344
PDID	123	ID	26.09	1.336	.000*
		TD	24.13	1.313	.000*
TD	122	ID	1.96	1.339	.344
		PDID	-24.13	1.313	.000*

**Pairs of groups significantly different at P < .05.*

Table 5: Scheffe Post Hoc Tests of Skills Acquisition by Treatment Groups

The results on Table 5 show that PDID teaching strategy is significantly differed from the ID and TD. TD learning strategy is not significantly differed from ID in skills' acquisition.

Research Hypothesis H_0^2: There is no significant effect of mathematical ability on senior secondary school students' mean scores in skills' acquisition.

There are no significant effect of mathematical ability on skills' acquisition ($F_{(2,340)} = 2.270$; $P > .05$) as indicated on Table 4. Hence, the null hypothesis H_0^2 is not rejected.

Research Hypothesis H_0^3: There is no significant effect of gender on senior secondary school chemistry students' mean scores in skills' acquisition.

The values of F were greater than 0.05 at level of significance for skills acquisition ($F_{(1,340)} = .021$; $P > .05$) as indicated on Tables 4. The null hypothesis H_0^3 is therefore not rejected.

Research Hypothesis H_0^4: There is no significant interaction effect of treatment and mathematical ability on senior secondary school chemistry students' mean scores in skills' acquisition.

The results presented on Table 4 on the significant interaction effect of treatment and mathematical ability indicate no significance at .05 for skills acquisition ($F_{(4,340)} = .520$; $P > .05$) since P values are greater than .05 as shown in Table 4. The null hypothesis H_0^4 is not rejected.

Research Hypothesis H_0^5: There is no significant interaction effect of treatment and gender on senior secondary school chemistry students' mean scores in skills' acquisition.

There is no significant interaction effect of the treatment and gender on senior secondary school students' mean scores in skills' acquisition ($F_{(2,340)} = 2.556$; $P > .05$) since F values are $P > .05$ as shown in Table 4. Hence, the null hypothesis H_0^5 is not rejected.

Research Hypothesis H_0^6: There is no significant interaction effect of mathematical ability and gender on senior secondary school chemistry students' mean scores in skills' acquisition.

There are no significant interaction effect of mathematical ability and gender on skills' acquisition ($F_{(2,340)} = .668$; $P > .05$) as indicated in Table 3. The null hypothesis H_0^6 is not rejected.

Research Hypothesis H_0^7: There is no significant interaction effect of treatment, mathematical ability and gender on senior secondary school chemistry students' mean scores in acquisition of skills.

From the results of the 3-way interaction of treatment, mathematical ability and gender on the chemistry students' indicated that $F_{(4,340)} = .289$; $P > .05$ for skills' acquisition in Table 4. Hence, the null hypothesis H_0^7 is not rejected.

Methodology

Quasi experimental research design of pre-test post-test control group was employed to investigate the effects of ID, PDID and TD on senior secondary school chemistry students in acquisition of life coping skills. The main and interaction effects of gender and mathematical ability on skills' acquisition were also examined.

Senior secondary form two (SS2) chemistry students were randomly sampled from nine secondary schools, in their intact classes in two Education Districts 2 and 4, Lagos State, Nigeria. The schools were randomly assigned to treatment groups of ID, PDID and TD and the numbers of students in each group were 114, 123 and 122 with total of 359 students.

The ID, PDIP and TD contained eight practical activities structured on chemistry contents of electrolysis, chemical kinetics, chemical equilibrium and redox reactions that students perceived difficult to learn. However, the modes of implementation of the guides were different depending on the learning strategies. The ID and PDID were student-centred learning strategies while TD is teacher-centred strategy. The learning activities were characterised by investigation, problem-solving and discussion. The ID and PDID students learning in a small discussion group where leader and recorder were appointed and these roles were rotated weekly.

The research instruments were Mathematical Ability Test (MAT) and Skills' Acquisition Test (SAT). MAT contained 20 items on proportionality, probability, statistics and algebra that have relationships with the chemistry contents. The students' scores on MAT were used to classify the sampled students into high, medium and low mathematical ability levels. The SAT consisted of 50-items that had two parts. The part 1 contained the science basic process skills of observing, measuring, classifying, predicting and inferring. These were 25 multiple-choice items that assessed only the analytical mode which required the students' choice of a set of experimental designs rather that actually designing an experimental set up (constructive mode). The instruments and guides were validated, their reliability determined and found to have high and positive coefficient values. Examples are:

1. A is 0.50M hydrochloric acid solution, B is 2 M sodium hydroxide solution. The temperature T_1 of the solution A was 29^0 C. When 10 cm ^{3} of the solution A was taken and mixed with $5cm^3$ of the solution B, the temperature T_2 was 28^0 C .The average temperature of the mixture is

A. $T_1 + T_2/3$ B. $T_2 + T_1 / T_2T_1$ C. T_1+T_2 / T_2 D. $T_1 + T_2 /2$

2. To a solution of sample K, $2cm^3$ of tetrachloroethane was added and $1cm^3$ of water. The mixture was vigorously shaken and put in a burette. Two immiscible layers were separate with a blue aqueous in the upper lower layer. It can be inferred that K.

A. is a mixture B. copper (II) ion present C. Iron (II) ion D. SO_4^{2-} present

The second part of the SAT contained life coping skills of critical thinking, communication, collaboration, accountability and leadership skills. The life coping skills items were self-assessment rating scales, contained five positive / negative statements on the scale of always, sometimes and never except for a critical thinking test that was a multiple choice test. The items were adopted from the 21st century skills Assessment Guides (Natural Resources Conservation Service, United States of America, 2007) for their validity and reliability. Each item on the rating scale of always, sometimes and never was scored 2, 1 and 0 mark (s) respectively except for the negatively stated statements that was reversed.

Examples are:

Accountability Always Sometimes Never

I assess my current priorities before accepting new one.

Collaboration

I ask questions to encourage my partner into full participation.

Communication

When I know what someone is going to say, I finish the sentence for him or her.

The critical thinking test a multiple–choice type that require knowledge of chemistry (or science) to answer them correctly. Example is:

A balloon can hold $100cm^3$ of air before bursting. The balloon contains 97.5 cm^3 of air at 5^0C. Will it burst when it is taken into a room of 25^0 C? (Assume that the pressure of the gas in the balloon remains constant).

- ✓ The balloon will not burst because it contains the same volume of air
- ✓ The balloon will burst because the gas pressure remains constant.
- ✓ The balloon will burst because of the temperature increase to 25^0 C
- ✓ The balloon will burst because the volume of the air in the balloon will increase beyond its capacity when the temperature increases to 25^0 C.

Five questions were structured on each of the skills.

The chemistry teachers in the sampled schools were trained for the implementations of the learning strategies as applicable to each school and assisted in administration of the tests. The MAT and SAT were pre-administered to the sampled before treatment. The treatment lasted for eight weeks. The SAT was re-administered to the students two days after the treatment.

Data obtained were analysed using descriptive statistics of mean and standard deviation to answer the research questions while analysis of covariance (ANCOVA) was used to test for significant difference where it existed. Scheffe post hoc tests were used to determine the direction of the significant difference.

IV. DISCUSSION OF THE FINDING

The treatment of the students with Investigate-Discuss, Predict-Discuss-Investigate-Discuss and Teacher Demonstration learning strategies had a positive impact on the students' acquisition of skills with slightly positive effect on the basic process skills than life coping skills. That is, the students acquired more skills of measuring, observing, inferring, classifying and predicting, which are the acts of doing science, becoming scientists and being gainfully employed as scientists than collaboration, critical thinking, communication, accountability and leadership. The life coping skills are also needed for employment and to sustain the job. There is significant main effect of treatment on the students' skills acquisition. The pattern of skills' acquisition is the PDID > TD > ID. This finding was in support with Hendry and Viney (2012) that found inquiry-based approaches such as problem and project-based learning are better in equipping students beyond the classroom, in their professional and working life than conventional methods.

The results further show that the students in the PDID learning strategy significantly differ from those in the TD and ID treatment groups in skills' acquisition. However, the students TD does not differ significantly from those in the ID treatment group in skills' acquisition. The superiority of Predict-Discuss-Investigate-Discuss strategy over Teacher Demonstration and Investigate-Discuss may be due to the active participations of the students in learning processes which involved manipulations of apparatus, identification of variables, making inference, experimenting and drawing conclusions. The interactions of the students with learning materials, collaborations with the peers in open discussions of predictions and outcomes of investigations may have given the students opportunity to acquire more basic process and life coping skills than the students in the ID and TD groups. The slight higher score observed with the students in the TD group than ID may be that the students in the TD had little exposure or not being exposed to practical activities before the treatment. The sudden exposure to practical activities and

explanations given by teacher on the underlying principles after the demonstrations may have given the students the opportunity to pay keen attention in observing, classifying variables, making predictions and inference. These may have assisted the students in the TD treatment group to acquire adequate skills higher than the students in the Investigate-Discuss strategy group who may have been used to practical investigations in chemistry.

The gender and mathematical ability of the students are not also significant for skills' acquisition in chemistry. Both male and female students achieved equally in skills' acquisition test. The finding is in support with Jack (2018) and Ogbeba and Ajayi (2018) that found gender has not having significant effect on skills acquisition in science. Students with low mathematical ability acquired the greatest skills followed by medium and the high mathematical ability students. Hence, mathematical ability also is not a necessity skills' acquisition in science.

V. IMPLICATION OF THE STUDY

The mean gain scores for ID and TD students were very low while that of PDID was relatively high in skills acquisition. The implication of this is that inquiry instruction is still very new to the students. The scarcity of the inquiry-based learning has resulted into low academic achievement in external examinations, lack of students' interest, attitudes, inadequate conceptual understanding and skills acquisition in science (Adeoye, 2016). Inquiry-based learning strategies should be adequately implemented in science classrooms to encourage students to test ideas, theories and develop team work in order to acquire necessary skills for their survival in world. Inquiry learning should be effectively structured to allow students' interpersonal communication, build confidence and taking responsibility of their actions and learning. These would foster the acquisition of skills for manpower and personal development that are needed for any nation to thrive.

VI. CONCLUSION AND RECOMMENDATION

The study concluded that:

- ✓ Senior secondary school chemistry students acquired more skills of basic process than that of life coping skills in ID, PDID and TD inquiry-based learning strategies.
- ✓ The pattern of senior secondary school chemistry students in skills acquisition is PDID > TD > ID.
- ✓ There is significant effect of treatment of senior secondary school chemistry students in the skills acquisition. That is, senior secondary school chemistry students differ significantly in their acquisition of skills based on the learning strategies.
- ✓ Mathematical ability of the senior secondary school chemistry students has no significant effect on their skills acquisition. However, the students with high mathematical ability students achieved highest in skills acquisition test followed by medium while the low mathematical ability achieve least in skills acquisition.
- ✓ Gender has no effect on senior secondary school chemistry students' skills acquisition. Both male and female students achieved equally in skills acquisition test.

The inquiry-based learning of ID and PDID learning are strongly recommended for teaching to develop science basic and life coping skills in science. However, there must be learning facilities for implementation of inquiry-based learning strategies. Training and retraining of teachers are very important for inquiry to thrive in science classrooms.

Chemistry teachers should be motivated to embrace learning by inquiry that allows students to manipulate teaching materials, collaborate and communicate with other students to build and acquire scientific and life coping skills.

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