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INFLUENCE OF INTEGRATING VIRTUAL AND PHYSICAL LABORATORIES ON KENYAN STUDENTS' ACQUISITION OF SCIENCE PROCESS SKILLS IN BIOLOGY

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ABSTRACT

Biology is the science of life. It enables learners to understand life processes, improvements in agriculture, advancements in medicine and how to address environmental challenges. Kenya Certificate of Secondary Education (KCSE) biology performance has been generally low for the past 5 years, with national mean score ranging between 18% and 35%. Learners struggle with acquisition of science process skills (SPS). These skills allow learners to describe events and objects, question what they have learnt and construct explanations based on the existing body of knowledge. These skills therefore are very imperative in enabling learners to perform above average especially in practical examinations in biology. This study therefore, determined the influence of using integrated virtual and physical laboratories on acquisition of science process skills (SPS). The study borrows heavily from constructivist learning theory as explained by the works of Vygotsky (1978) and Piaget (1973). Quasi-experimental research design, using Solomon fourfold nonequivalent group design was used to execute the study. The study targeted a population of 1,946 form two learners and 26 Biology teachers of Butere sub county Kenya. The study sample size was 198 students and 4 teachers of biology both sampled using simple random sampling and purposive sampling. Acquisition of SPS was the dependent variable, while instructional strategy at two levels; use of integrated virtual and physical laboratories and Conventional Instructional Strategies formed the independent variable. The intervening variable was the students' attitude in biology. Piloting of the study was done two weeks before the actual study in two secondary schools within Butere Sub County. Data was collected using Integrated Science Process Skills test (ISPST). The research instrument was validated using Expert Judgment while reliability was determined using Kuder- Richardson formula (K-20) using data obtained from the pilot study. The instrument reliability coefficient was 0.877. Data was analyzed

descriptively using mean scores percentages and standard deviations. Null hypothesis was tested at statistical significance level of alpha 0.05 using One-Way ANOVA and independent sample t- test. Findings revealed that use of integrated virtual and physical laboratories had significantly superior influence on students' acquisition of SPS relative to the use of Conventional Instructional Strategies.

KEYWORDS: Science Process Skills, Integrated Virtual and Physical Laboratory

INTRODUCTION

Biology pervades every aspect of life. Human beings depend on living things for food, fuel, homes, medicine, personal care among others. Biology learning involves understanding of the living world and the way its many species functions, evolve and interact. World over, biology subject is seen majorly as a practical endeavor. This is one of the reasons why teaching methods in biology are judged based on the practical activity engaged by both students and teachers. A critical examination of performance in biology at national level (KCSE) reveal that performance of this important subject in practical tests (paper 3) has always been relatively lower than performance in theory tests (paper 1 and paper 2). Consider statistics below.

Table 1: National Biology mean score performance of 2019 to 2023

Year	Overall Score	Paper	Mean Score	Mean Percentage
2019	35.26	Theory	18.00	52.94
		Practical	16.00	47.06
2020	31.455	Theory	23.27	54.62
		Practical	19.33	45.38
2021	31.695	Theory	22.15	57.55
		Practical	16.34	42.45
2022	32.78	Theory	19.58	59.90
		Practical	13.11	40.10
2023	32.52	Theory	21.43	53.05%
		Practical	18.96	46.95

Source: The year 2019 to 2023 K.C.S.E KNEC report.

From the Table 1 above, it can be observed that, the overall performance of biology tests at national level (KCSE) has always been below average (32.298). Wabuke (2012) attributes this low performance in biology to pedagogical approaches adopted by biology teachers. Some teaching approaches are superior to others with regard to achievement in biology. Table 1 above, also points out on a clear trend that shows that performance in theory papers has always been relatively higher than that of practical papers of the same years. According to KNEC reports of 2018 – 2022, this dismal performance in biology practical tests has been attributed to majority of learners lacking science process skills. Sshana and Abuliddeh (2020) supports the claim arguing that the skills are very imperative for learners to perform scientific investigations, make scientific observation, necessary conclusion and even prediction of future events with accuracy. Ngakhala, Toili and Tsingalia (2017) insists on the need for educators to adopt pedagogical approaches that improve acquisition of SPS if learners were to perform well in practical tests.

SPS are skills used by scientists to investigate. Learners use science process skills during scientific investigation for discovery of new scientific knowledge. Opara (2011) posits that, science process skills allow learners to describe events and objects, question what they have learnt, construct explanations based on the established body of knowledge. SPS can be grouped into two, namely, integrated science process skills (ISPS) and basic science process skills (BSPS) (AAAS, 1993). BSPS include Inferring, observing, communicating, classifying, predicting and measuring (Rambuda & Fraser, 2004). BSPS form the basis for mastering ISPS. Several BSPS are necessary in mastering of a particular ISPS. These ISPS are necessary in carrying out scientific investigations (Rambuda & Fraser, 2004). ISPS include, controlling variables, interpreting data, formulating hypothesis, defining operationally, experimenting and formulating models.

Table 2: Integrated science process skills.

Skill	Description
Experimenting	A skill used in Carrying out scientific investigations by following certain procedures that allow verification of results by repeating the procedures.
Formulating hypothesis	A skill used to make an intelligent guess during scientific investigation.
Data interpretation	Evaluating and formulating scientific inferences from collected data.

Defining operationally	Skill used to explain how each variable will be measured in experiment e.g. infant mass will be measured in kilograms per months.
Controlling variables	Skill used to vary independent variables to observe the effect of variation on dependent variables.
Formulating model	Skill used in creating mental of physical models that describe interrelationship of scientific ideas

Source :(AAAS,1993)

According to CEMASTE A (2011), proper use of science laboratories when teaching biology provides enabling environment for learners to acquire SPS and improve performance in biology. This because it is in the laboratory where learners get a chance to practice on these skills by manipulating different variables and observing the outcome of their manipulation. According to Enneking et al. (2019), learners exposed to integrated virtual and physical laboratories are not any different with those exposed to only physical laboratories as pertains to acquisition of SPS. This study findings are strongly supported by (Miller, Carver & Roy, 2018; Hensen & Barbera, 2019; Thees et al. 2020). According to Olympiou et al. (2008), integrating virtual and physical laboratories presents a superior experience that allow students to acquire SPS relative to physical laboratories. This position is strongly supported by (Brinson, 2015; Sypsas & Kales, 2018). These empirical studies present contradiction in literature with regard to which laboratory experience enables learners' to sufficiently acquire SPS. Besides the contradictions, the studies mentioned above were done in countries outside Kenya with different education system and curriculum needs, therefore, their findings cannot be used to provide solutions to Butere Sub County where acquisition of SPS among learners is very poor as seen in their dismal performance in biology.

REVIEW OF RELATED LITERATURE

Enneking et al. (2019) studied hybrid laboratory environment, the undergraduate chemistry student's attitude and acquisition of SPS in USA. Hybrid laboratory referred to laboratory learning experiences that were made up of both physical and virtual laboratory experiences. Pure experimental design was used with one group being exposed to hybrid laboratory while the other to traditional physical laboratory. Data was collected using questionnaires. From the findings, learners exposed to hybrid laboratory were not any different from those exposed to only physical laboratories with regard to acquisition of SPS. The two groups in the study were in the same university hence likelihood of Hawthorne effect (Mugenda, 2003).

Hensen and Barbera (2019) compared chemistry experiments done using virtual laboratory and those done in physical laboratory with regard to acquisition of SPS. Their study adopted experimental design. Half of the sampled students were performing physical hands-on experiment while the other

half performed similar experiments in computer mediated environment. Achievement of the experimental objectives between the two groups was compared. Based on the comparison it was established that virtual laboratories were just as efficient as physical laboratory with regard to enabling learners acquire SPS. The study adopted Solomon four design that allows for only four intact classes to be used in the study, this type of sample is not properly randomized and therefore findings of such study may not be generalized to other places like Butere Sub County Kenya.

Miller, Carver and Roy (2018) comparatively examined Face-to-face laboratory and virtual laboratories with regard to acquisition of SPS in USA. The study involved undergraduate students in physical science class. The study adopted experimental research design. The study findings revealed that both laboratory experiences provided learners with equal opportunity to acquire SPS. There was no significant difference with regard to acquisition of SPS between the two groups, control and experimental.

Olympiou et al. (2008) compared the influence of using combined physical and virtual laboratories on promoting learners' conceptual mastery and practical skills in the domain of heat and temperature. The study adopted experimental design. The study had three and one experimental and control groups respectively. Groups in the experimental cluster, were exposed to combined virtual and physical laboratory but in different sequence. Findings revealed that use of combined virtual and physical laboratory provided superior experiences with regard to acquisition of practical skills. However, the study did not use Solomon four design hence pre- treatment effects may not have been checked.

Brinson (2015) analyzed empirical studies in the recent past (post – 2005) that compared learning outcomes when both integrated virtual and physical laboratory and physical laboratory are used. Learning outcomes assessed included practical skills (SPS). Findings from the majority of studies (89%) revealed that learning outcomes were high when integrated virtual and physical laboratory are used than when only physical laboratories are used.

Sypsas and kalles (2008) investigated influence of using virtual labs on biology with regard to acquisition of cognitive skills among learners. Virtual laboratory used in various learning settings. The findings revealed that use of virtual laboratory led to enhanced acquisition of cognitive skills among learners.

Based on these empirical studies discussed above, the issue of which laboratory experiences present better opportunity for learners to acquire SPS has not been conclusively established. Whereas a number of scholars (Olympiou et al. 2008; Brison, 2015; Sypsas & Kalles, 2018) holds the position that integrated virtual and physical laboratory present superior experiences to students with regard to acquisition of SPS, others (Enneking et al. 2019; Miller, Carver & Roy, 2018; Hensen & Barbera, 2019) holds the view that both laboratory experiences have no significant differences with regard to

acquisition of SPS among learners. These research conclusions are contradicting and therefore making it necessary for further research.

MATERIALS AND METHOD

Quasi experimental design, specifically Solomon four none equivalent group design, was adopted to implement the study. The design has advantage of checking the effects of pre-treatment evaluation on the post-test (Mubichakani, 2012).). The design involves forming two control and experimental groups as explained using the Table 3 below.

Table 3: Showing how the design was used.

Clusters	pre-tested	intervention	post-tested
Experimental 1	G ₁	X	G ₂
Control 1	G ₃	-	G ₄
Experimental 2	-	X	G ₅
Control 2	-	-	G ₆

Source: Sekaran (2006)

Key: G₁ and G₃ represent pre-tests

G₂, G₄, G₅ & G₆ represents post-test

X represents teaching intervention

Experimental one and two which constitutes experimental group was given the intervention (integrated virtual and physical laboratory experience) while control groups were taught the topic of interest using conventional teaching methods which included exposure to physical laboratories. The learners in experimental group were taught using integrated virtual laboratory in constructivism approach. Interactive simulations were manipulated and learners expected to make observation, inferences, predict possible outcomes of manipulation, formulating models among other skills. Experimental group one was pre-tested, given intervention and then post-tested. Learners in the Experimental group two only receive treatment and then post-test. Control group one was subjected to pre-test, control conditions and finally post-test. Control group two only received control conditions and then post-test. The treatment in this study involved facilitating learning of the topic gaseous exchange in plants and animals using integrated virtual and physical laboratory.

The virtual laboratory experiences were from PhET softwares and simulations. The virtual laboratory was used jointly with physical laboratories to teach concepts of gaseous exchange. Physical laboratory was used majorly during lesson development to allow learners investigate certain concepts under gaseous exchange in plants and animals like structure, adaptation and function of fish gill (fish as

physical specimen). Virtual laboratory was majorly used at the end of the lesson as means of connecting theoretical knowledge with practical and visual application. This created mental images of the concepts in the mind of learners enabling them to be able to manipulate what they learned abstractly. Learners also were able to repeat experiments, analyse data and correct mistakes. Virtual laboratory was also employed during lesson development in areas where physical laboratory experiments could not be carried out for example breathing process in fish and frog, counter current flow of water over fish gills among other abstract areas. Learners in the control class were exposed to the conventional teaching and learning approaches being employed in schools currently in Kenya. The study was conducted for 4 weeks. Teachers were trained on the best ways to integrate virtual and physical laboratories in teaching the topic of interest prior to commencement of the study.

The study location was Butere Sub County Kenya. The sub county is located on the western part of Kenya and specifically in Kakamega County. The sub county borders Mumias east on the northern side, Lurambi on the eastern side, Khwisero on the southern part and Mumias west on the western side. The population of the study area is 139780 living in an area estimated to be 210KM² according to data held at Kakamega county website (www.kakamega.go.ke). The sub county lies between latitude 0o 07'30" North and 0o 15" North and longitude 34o 32" East and 34o 57'30" East. The sub county has six wards namely Butere township, Central Marama, Marenjo, North Marama, Manyala and West Marama. Sub county literacy level stands at 72.7%. Majority of the students perform dismally in biology in the national examinations as reported by Kenya National Examination Council in the previous years. Target population for the study was 1,946 form two biology students. Form two biology students were targeted because the topic of interest (gaseous exchange) is a form two topic. The topic is among topics which is highly tested in KCSE examination (KNEC reports, 2019-2023). Purposive sampling based on availability of electricity, computers, projectors and well equipped laboratory was used to sample four schools to be involved in the study. Two classes out of the four were exposed to the treatment while the other two classes were taught using conventional teaching method being practised in schools today. Mugenda and Mugenda (2003) posits that each group in the experimental studies should be at least 30 students. This is an equivalent of a normal class. This study therefore used four classes from four different schools to represent the four groups described in the design. Simple random sampling was used to place schools and classes into control and experimental groups. 198 form two students from four classes in four different schools formed the sample size. The four classes had the following number of learners, class A (46), class B (56), class C (54) and class D (42). The minimum class size for experimental studies should be 30 learners (Mugenda & Mugenda, 2003).

Integrated science process skills test (ISPST) was used to assess learners' acquisition ISPS after the treatment. The instrument contained 30 items with each item having 4 suggested responses (one correct response and 3 distractors) for student to pick the correct response. The instrument measured the following five integrated SPS, experimenting, formulating hypothesis, controlling variables, data interpretation and defining operationally and formulating models. The instrument has 6 items on each

of the 5 skills being measured. ISPST was adapted from Kazeni (2005). Construct and content validities for ISPST was determined by experts in science education Maseno University. This included checking of language level and eliminating of ambiguity that comes with rewording of items. Piloting of the ISPST was done in one school (50 students) with relatively similar characteristics as those sampled and the kuder-Richardson formula 20 used to determine reliability coefficient of the instruments. The above piloting sample size was derived from studies of Mugenda and Mugenda (2003) who posits that the acceptable sample size for pilot studies in experimental studies should be at least 10% of the sample size to be used in the actual study. ISPST had alpha coefficient of 0.877 which is higher than threshold set by George & Mallery, (2003).

Data from ISPST was analysed as follows. Mean and standard deviation for the four groups was calculated. One-way ANOVA and t- test were used to determine if there exist any statistical differences among the four groups with regard to acquisition of SPS. The results of this test were used to answer study objective which was to establish the influence of integrating virtual and physical laboratories on acquisition of integrated SPS in biology. Refer to Table 4 below for data analysis summary.

Table 4: Showing data analysis summary

Objective	Independent variable	Dependent variable	Statistical tool to be used
To establish the influence of integrating virtual and physical laboratories on students' acquisition of SPS in biology	Integrated virtual and physical laboratory	Acquisition of SPS	ANOVA & t-test

RESULTS AND DISCUSSION

Before embarking on actual data analysis, a number of preliminary analysis were done to establish the requisite demographic information about the respondents.

Table 5: Summary of demographic data of study respondents

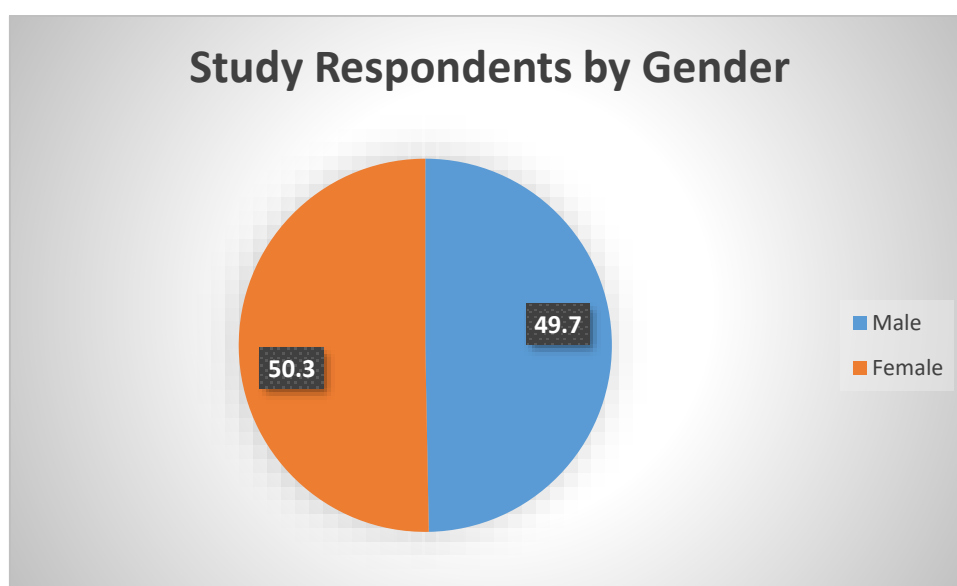
Group	Gender			Percentage
	Male	Female	Total	
Experimental	47	47	94	50.82%
Control	45	46	91	49.18%

Total	92	93	185	100%
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Source: Research Data, 2025

From the table, it can be observed that the two groups, experimental and control were of almost equal sizes. Of these, 93 were female and 92 male, implying that female learners were relatively more (50.3%) than males (49.7%).

Figure 1: showing study respondents by gender



Source: research data, 2025

To check on the assumptions of ANOVA, Shapiro – wilk test was used to check the normality of data of the students' scores in the ISPST. Results of this test gave p-value of $[w(185) = .969, p = .283 \text{ at } \alpha = .05]$ which is non-significant, indicating that the scores of ISPST were normally distributed, hence normality assumption was met. Another assumption of ANOVA is that the groups sampled should be of equal variances. Levene's tests of homogeneity of variance was used to test this assumption which gave a p value $[F(1, 181) = 6.191, p = .211 \text{ at } \alpha = .05]$ which is non-significant. This indicates that there were non-significant differences in variances between the data sets under investigation hence this assumption was met.

The study objective was to establish the influence of integrated virtual and physical laboratories on learners' acquisition of SPS in biology. To meet this objective, data was collected using ISPST. Learners sat for the test twice, i.e. prior to the intervention as a pre-test and after the intervention as a post-test. The intervention was use of integrated virtual and physical laboratories as teaching strategy. Below is a summary of pretest performance between the experimental and control groups.

Table 6: Means and Standard deviations of pretest.

Test		N	Mean score	Standard deviation
ISPST	Experimental Group 1	46	42.83	3.627
	Control Group 1	46	42.47	3.116

Source: Data, 2025

n = 92

The two groups presented in the table 6 above i.e. Experimental group one and control group one was pretested using ISPST and their means were 42.83 and 42.47 respectively. These means scores, though low, suggests that, the two groups were almost on the same level with regard to acquisition of SPS at the beginning of the study as revealed by very small mean difference of 0.36. An independent samples t-test was carried out to determine if the difference in the pretest means was significant or not. The t-test was performed at a significance level of $\alpha = .05$. The test findings are as tabulated below.

Table 7: showing t-test results

Variable	t-test of Means				
	t	df	Sig. (2-tailed)	Mean Difference	Std Error Difference
ISPST	.186	45	.853	.082	.109

Source: Research Data, 2025

From the table, the t test had a p value of .853 which is greater than alpha value ($\alpha = .05$), it was therefore concluded that there was no significant difference between the experimental group 1 and control group 1 mean scores in the pre-test. The two groups were at the same level in terms of acquisition and application of SPS at the beginning of the study. After pre testing selected groups, the two experimental groups were subjected to intervention. The two control groups on the other hand, were not exposed to the intervention. All the groups sat for ISPST as a post test to measure their acquisition of SPS. Results are as tabulated below.

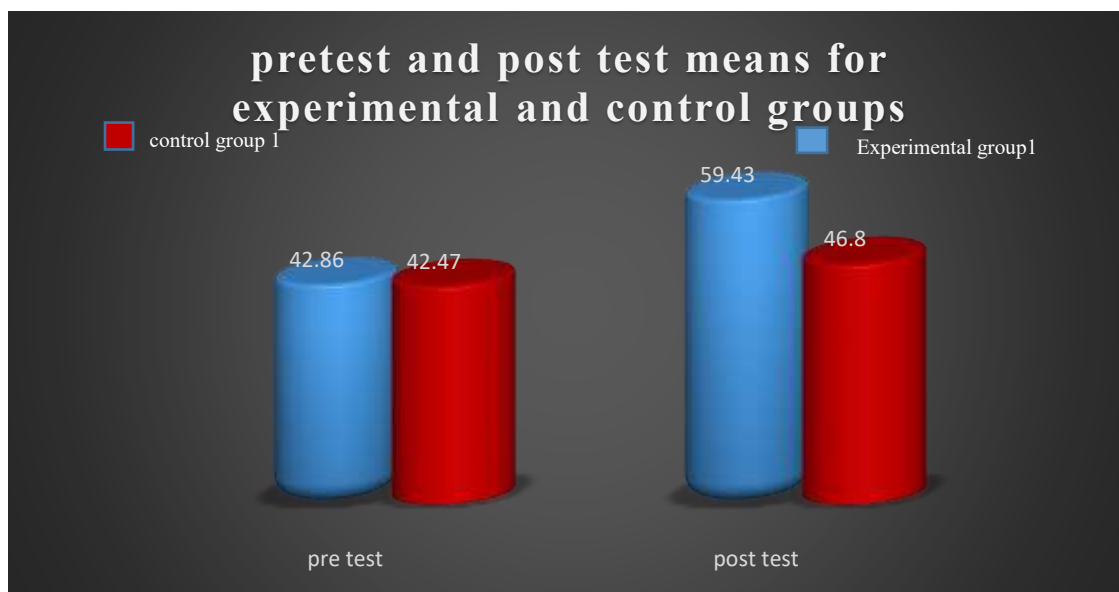
Table 8: Means and Standard Deviations of ISPST

Groups	<i>N</i>	Mean	Standard Deviation
Experimental group 1	46	59.43	3.453
Experimental group 2	48	59.43	3.165
Control group 1	46	46.80	2.385
Control group 2	45	45.57	4.375

Source: Research Data, 2025**N = 185**

From the table, the experimental groups performed relatively better than the control groups. The experimental group had relatively larger gain in means between pretest and posttest (16.60%) compared to control group (4.33%) as illustrated below.

Figure 2: Gain in means between pretest and posttest



Source: research Data, 2025

An independent sample t-test at significance level of (α) .05 was therefore used to determine whether the mean gains were statistically significant or not.

Table 9: t-test for gain in means of the experimental group 1

Variable		Paired difference			
	<i>t</i>	<i>df</i>	Sig.(2-tailed)	Mean Difference	Std Deviation
ISPST	9.829 45	.000	4.978	3.435	

Source: Research Data, 2025

$n = 46$

The t-test had a p value of .000 which is less than alpha value ($\alpha = .05$) showing that, the difference in the means between pretest and posttest for experimental group 1 was statistically significant. This significant difference in means was attributed by the researcher on the influence of the intervention. One way analysis of variance (ANOVA) was used to test the study hypothesis which was, “There is no significant influence of integrating virtual and physical laboratories on the learners’ acquisition of science process skills in biology.

Table 10: ANOVA results for the Post-test Scores in ISPST

	Sum of Squares	df	Mean Square	F	P value
Between Groups	732.952	3	244.317	21.006	.000
Within Groups	2105.188	181	11.631		
Total	2838.141	184			

Source: Research Data, 2025

From table 10 above, $F(3, 181) = 21.006$, $p = .000$. The p value of less than alpha value of .05 ($p < .05$) lead the researcher into rejecting the null hypothesis hence the conclusion, learners mean scores in the ISPST from the four groups were not equal. A post hoc test was carried to determine where the differences occurred. The test was carried out using Least Significant Difference (LSD) procedure at $p < .05$ level.

Table 11: Post-Hoc test of ISPST Means for the Four Groups

(I) Index1	(J) Index1	Mean Difference (I-J)	Std. Error	Sig.
Experimental 1	Control 1	3.783*	.711	.000
	Experimental 2	-.007	.704	.992
	Control 2	4.159*	.715	.000
Control group 1	Experimental 1	-3.783*	.711	.000
	Experimental 2	-3.790*	.704	.000
	Control 2	.377	.715	.599
Experimental group 2	Experimental 1	.007	.704	.992
	Control 1	3.790*	.704	.000
	Control 2	4.167*	.708	.000
Control group 2	Experimental 1	-4.159*	.715	.000
	Control 1	-.377	.715	.599
	Experimental 2	-4.167*	.708	.000

*. The mean difference is significant at the 0.05 level.

Source: Research Data, 2025

N = 185

From the post hoc test results above, experimental groups means were significantly different relative to control groups means. This was attributed to the intervention provided for by the researcher on the

experimental group. This therefore confirms that the intervention had positive influence on acquisition of SPS

CONCLUSION

Based on the statistical evidence from data collected in this study, it was concluded that students who were taught biology through the use of integrated virtual and physical laboratory sufficiently acquired science process skills relative to those who were taught the same subject using conventional teaching methods. This positive influence of integrated virtual and physical laboratory on acquisition of SPS can be attributed to the fact that learners were able to visualize all the concepts and create mental images of what they learnt hence more deeper understanding.

These findings of this study are in agreement with those of Olympiou et al. (2008) who compared the effect of using combined virtual and physical laboratory on promoting learners conceptual understanding and practical skills in the domain of heat and temperature. The study adopted experimental design with three groups as experimental group and one control group. Findings revealed that use of combined virtual and physical laboratory provided superior experiences with regard to acquisition of practical skills. Another similar study by Brinson (2015) reviewed recent empirical studies that compared student learning outcomes when both integrated virtual and physical laboratory are used. Learning outcomes assessed included practical skills (SPS). Findings from the majority of studies (89%) revealed that learning outcomes were high when integrated virtual and physical laboratory are used than when only physical laboratories are used.

However, contrary to these findings is a similar study by Enneking et al. (2019) who studied hybrid laboratory environment and the undergraduate chemistry student's attitude and acquisition of SPS in USA. Hybrid laboratory referred to laboratory learning experiences where learners were exposed to both physical and virtual laboratory experiences. Pure experimental design was used with one group being exposed to hybrid laboratory while the other to traditional physical laboratory. Data was collected using questionnaires. From the findings, learners exposed to hybrid laboratory were not any different from those exposed to only physical laboratories only with regard to acquisition of SPS. However, the two groups in the study were in the same university hence likelihood of Hawthorne effect (Mugenda, 2003).

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