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THE EFFECT OF INSTRUCTIONAL INTEGRATION OF INVESTIGATIVE EXPERIMENTS ON THE ACQUISITION OF SCIENCE PROCESS SKILLS AMONG PHYSICS LEARNERS IN SECONDARY SCHOOLS IN THARAKA-NITHI COUNTY, KENYA

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ABSTRACT

Physics is a science that is driving technological advancements in the Industrial Revolution as it is the backbone of modern society. Essential technologies such as telecommunication, automobiles, modern construction among others are pegged on the foundational principles of physics. Physics is a major science embraced in high schools as it fosters problem-solving, analytical, and critical thinking skills in learners. The Kenyan government has made significant efforts to enhance learners' interest in physics and other Science Technology Engineering and Mathematics subjects. For instance, the Ministry of Education has introduced micro-kits Science Equipment Production Unit, and virtual labs to promote laboratory investigative approach in schools. Despite the interventions by the government through the Ministry of Education, low performance in Physics has remained persistent in Kenya Certificate of Secondary Education examinations. Various studies have shown that the integration of investigative experiments in teaching science subjects enhances the acquisition of science process skills. Therefore, this study investigated the effect of Instructional Integration of Investigative Experiments on the acquisition of Science Process Skills among physics learners. The study employed Solomon's fourfold research design. The research was carried out in four sub-county secondary schools in Tharaka-Nithi County which were selected randomly from 135 sub-county secondary schools selected purposively. The target population was Form two Physics learners. The accessible sample size was 120 learners from the four sampled schools. Data was analyzed using SPSS by implementing the Unpaired Wilcoxon test, Paired Wilcoxon test, and Kruskal Wallis test. The findings of the study

indicated that Instructional Integration of Investigative Experiments had a significant effect on the acquisition of Science Process Skills among physics learners. The curriculum developers should integrate investigative experiments in small groups or as individuals in Physics lessons to enable the practical aspect of learning. The findings of this study may help curriculum developers to integrate investigative experiments in Physics lessons to enable the practical aspect of learning. Further, the findings of the study may help schools to organize frequent investigative experiments for learners to participate and improve their understanding of physics to yield the best physics mean scores.

KEYWORDS: *Investigative Experiments, Science Process Skills, Hooke's Law*

1. Background Information

Physics is a science subject widely acknowledged for providing learners with science and technology knowledge and skills. The subject is globally recognized for the advancement of technology and is applied majorly in space exploration, transport systems, modern modes of communication, and medicine (Euler, 2004). Gathage et al., (2021) notes that teachers' effectiveness in explaining physics concepts, theories, laws, and principles is critical in enabling students to successfully develop any technology for the skills and knowledge acquired. Investigative Experiment is one of the major scientific practices as recognized by the Interactive-Constructive-Active-Passive framework (ICAP) that teachers can employ to effectively deliver content in science subjects (Chen & Terada, 2021). This scientific practice is a type of Investigative Practical-Based Instruction (IPBI) structured to provide learners with scientific understanding. The IPBI is student-centered and involves the full participation of learners in learning to promote self-responsibility (oghly, 2023). The teaching strategy involves problem-solving, fieldwork, project work, and case studies.

Studies have shown that IPBI teaching method is effective in enhancing student's Science Process Skills (Çakiroğlu et al., 2020). However, Lestari and Oktavian (2023) argue that despite IPBI's effectiveness in Science, Technology, Engineering, and Mathematics (STEM) education teachers believe that there are difficulties in implementation. Akuma (2017) believes that teachers have not experienced investigative-based experiments themselves hence their lack of appreciation for the method's value. As a result, there has been the need to change teachers' and stakeholders' perceptions towards implementation of IPBI to enhance the acquisition of the Science Process Skills. A study by Rogers & Revesz (2019) among Malaysian science learners to evaluate their understanding of scientific concepts showed that learning was more effective among learners when teachers employed investigative experiments in teaching science subjects. The study recommends equipping science teachers with investigative practical skills to enhance their teaching effectiveness. In the Philippines, the Ministry of Education has established an IPBI strategy to introduce the Science Curriculum Improvement Strategy (SCIS) with three phases including exploration, concept introduction, and concept application (Crujeiras-Pérez & Jiménez-Aleixandre, 2019). According to Zhou & Okahana (2019), students in the 21st century demand learning activities that involve self-discoveries, interactions, and collaboration to explore their opinions, interests, beliefs, and curiosities. Investigative experiments enhance students' capabilities to develop research skills, critical thinking, collaboration, and scientific communication.

South Africa's high school curriculum for science subjects requires the assessment if learners in two practical investigations at the Further Education and Training phase for grades 10-12. The country's department of education emphasizes the need for practical investigations in chemistry and physics (Shana & Abulibdeh, 2020). The practical investigations equip learners with a wide range of skills including data interpretation, problem-solving, planning and conducting investigations, scientific arguing, and presentation. A study conducted among grades 10-12 learners

in Motheo District, South Africa to investigate the acquisition of science process skills from an investigative experiment showed that 82% of the learners acquired moderate levels of the skills (Mupira & Ramnarain, 2018). According to the study, science teachers prefer the use of cookbook laboratory exercises which enable students to follow a series of instructions and replicate the phenomenon over inquiry-based investigative experiments. However, the study recommended the adoption of inquiry-based investigative experiments among science teachers in South Africa because the strategy enables students to develop problem-solving capabilities and sharpens their critical and analytical thinking. Following the findings from Mupira & Ramnarain's (2018) study and other related studies, the MOE of South Africa refined the Prescribed Practical Activities (PPA) and Recommended Practical Activities (RPA) in the new curriculum to promote inquiry in teaching and learning of science subjects.

In Kenya, studies have pointed out significant efforts towards the implementation of the IPBI in secondary schools. However, the studies point out numerous challenges faced by teachers in the implementation process. For instance, 28% of learners and 44.3% of teachers in Marakwet West Sub-County in Uasin Gishu County reported difficulties in the implementation of an experimental approach that sought to enhance students' understanding of the application of the moment of force concept in Physics (Chepkwony et al., 2021). The lack of laboratory facilities and other resources was a major challenge in the implementation of investigative experiments. As a result, many physics teachers ended up employing conventional teaching methods which is limited in the acquisition of science process skills. Langat et al., (2022) indicate that low knowledge and skill levels are major impediments to embracing inquiry-based teaching among teachers in Kenyan secondary schools. Despite emphasis by the Kenyan government through the Ministry of Education on quality teaching and learning of STEM subjects, there exist gaps that require to be addressed.

Figure 1 below shows that the average physics performance in Tharaka-Nith County between 2016 and 2022 was below the national level. The performance at both levels during this period has been below 5 which is far below C+ a requirement for university entry grade (KNEC, 2016-2022).

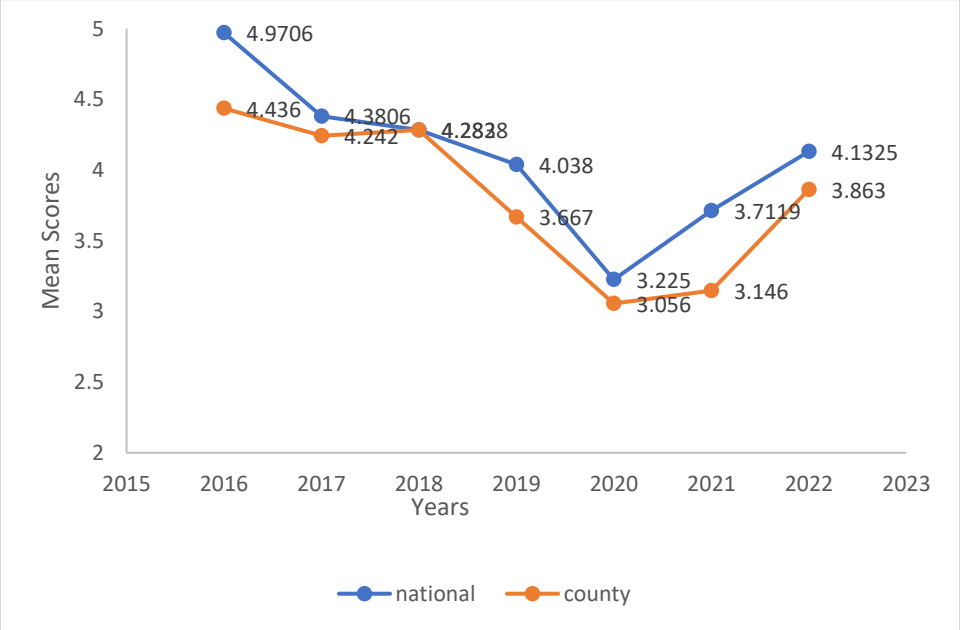

Figure 1: KCSE Physics Achievement by Students, from 2016 to 2022

Source: KNEC Reports from 2016 to 2022

Further, the KNEC report indicates that Hooke's Law is one of the most tested topics in physics Paper One between 2017 and 2023. Low performance in questions on Hooke's law has been reported for the same period. The poor performance is attributed to the problems answering questions that require applications of concepts derived from laboratory investigations. Additionally, limited laboratory practicals and inadequate teaching strategies by teachers are causes of the poor performance in Physics at KCSE. Schools overly use conventional teaching strategies with the practice of investigative-based science education remaining underdeveloped. Though several studies point out the challenges facing the use of investigative experiments in schools, information about the influence of investigative experiments in Hooke's Law among physics learners in secondary schools remains scanty. Therefore, this study sought to investigate how the integration of investigative experiments among physics learners in Tharaka-Nithi County during the Hooke's Law topic would influence their acquisition of Science Process Skills.

2. Statement of the Problem

Investigative experiments are essential for teaching science subjects which are a pre-requisite for technological and industrial development. However, schools in Kenya have been reluctant to adopt this teaching method despite its effectiveness due to scarcity of resources and limited knowledge and skills among teachers on its implementation. As a result, there have been persistent low KCSE academic achievements in physics at national and county levels. Efforts by the government to reskill and upskill teachers handling STEM subjects, construct laboratories, and provide schools with necessary science laboratory equipment remain inadequate to enhance performance. Empirical evidence shows that the Integration of Investigative Experiments by teachers is one of the most effective techniques for acquiring SPS among Physics learners in secondary schools. There have been concerns with performance of the Hooke's Law which is a highly tested topic but lowly performed by most students during KCSE. This study focused on investigation of the level of integration of investigative experiments among physic teachers for acquisition of SPS in secondary schools in Tharaka-Nithi County.

3. Objectives of the Study

The objective of the study was to investigate the effect of instructional integration of investigative experiments on the acquisition of science process skills among physics learners.

4. Hypothesis

Instructional Integration of Investigative Experiments has no significant effect on the acquisition of Science Process Skills among physics learners in Tharaka Nithi County.

5. Methodology

The study applied a nonequivalent control group pretest-posttest quasi-experimental design. This design is preferred when an intervention is assigned to participants non-randomly. The quasi-experimental research design was appropriate because of its suitability in accessing the cause-effect relationship between dependent and independent variables and comparing various treatment groups (Gopalan et al., 2020). The schools sampled for this study were assigned as either a control or experimental group. Further, the study employed Solomon's fourfold group design to have a four-group comparison which includes two treatment and two control groups.

The study targeted 135 public secondary schools in Tharaka-Nithi County. The 135 schools consisted 53, 45, and 37 girls', boys', and mixed secondary schools, respectively. The population of interest was form two physics students in public secondary schools because Hooke's Law topic considered in the investigative experiment is covered in this class. The topic was selected for this study based on evidence from KNEC reports that the topic has

been tested for the last six years and the performance on Hooke's law has been poor over the same period. The 135 schools were sampled purposively to obtain public secondary schools in the county categorized under the sub-county level. About 80% of schools in Tharaka-Nithi county fall under the sub-county category.

Purposive sampling was suitable for the study because it helped the researcher utilize cases that provided relevant information based on the study objective. The sampled schools were distant from each other geographically to avoid information leakage. The sampled schools were assigned either to the experimental or control group with each school providing a form two class that was to be part of the study. A simple random sampling was employed to select four schools that were effectively used in Solomon's fourfold design. According to Wu & Thompson (2020), simple random sampling is appropriate because it helps obtain a representative sample of the entire population. In case a school had more than one stream per class, one stream was selected randomly for the study. The study involved 120 Form two learners from the four schools. A 40 marks test was administered to the sample Form two physics students on the Hooke's Law topic. The test's questions were constructed from the past KCESE Physics paper one exams. The questions were standardized and modified to ensure suitability for use in the study. The sampled students used 40 minutes to complete the 40 marks test. The stipulated time was matched to a single physics lesson which is adequate to complete a 40 marks test. The questions in the test were based on Blooms taxonomy of cognitive domains with the assessment of each item focusing on a specific Science Process Skill.

The study conducted a physics achievement test (PAT) among the Form Two physics learners from the four sampled sub-county schools to obtain means scores for analysis. The test was used to determine the academic achievement gains from the integration of investigative experiments. The test was administered at two levels with the first level administered before the intervention (pre-test) and the second one after the treatment (post-test). The treatment or intervention in this study was administered in the form of instructional materials. The pre-test and post-test were administered to the same groups of students (control and treatment groups). The two tests were similar to provide a common measure to assess learners' performance in the experimental and control groups. The scores from the two tests were tabulated and analyzed. Interpretation of the learners' scores was based on a qualitative scale as shown in Table 1 below. Assuming a mean score of X the formulae adopted by this study for converting the mean scores to mean % score is $\frac{X}{40} * 100$.

Table 1: Mean Score and Qualitative Interpretation of the Data

Mean % Score			Qualitative Interpretation
90	-	100	Outstanding
80	-	89	Very satisfactory
70	-	79	Satisfactory
60	-	69	Fair
50	-	59	Meet expectations
0	-	49	Do not meet expectation

The reliability test of the PAT was conducted using the Cronbach's alpha. The pre-test had an alpha value of 0.745 and a post-test value of 0.763 which is considered reliable given the threshold value of 0.7 (Hashim et al., 2020). Raw data from the PAT was entered into MS Excel and later imported into SPSS for cleaning and analysis. The analysis involved both explorative and inferential approaches. Explorative analysis was in the form of boxplots. Inferential techniques used included unpaired Wilcoxon rank sum tests for test scores for students from independent

groups and paired Wilcoxon signed rank tests from the test scores for students from dependent groups. The paired and unpaired Wilcoxon tests are alternatives for independent sample t-test and paired sample t-test, respectively, and were suitable because the data deviated from normality. Further, the Kruskal Walis Test was used to determine whether the four treatment groups had significant differences. The test is a non-parametric method used in place of ANOVA when the data deviates from the normality assumption.

6. Results and Discussion

To establish whether Instructional Integration of Investigative Experiments has significant effect on the acquisition of Science Process Skills the test scores from the PAT were analyzed. The section presents the findings and discussion.

6.1. Comparison of the Independent Groups

Before the administration of the treatment, an assessment was conducted between the control and intervention groups, and scores were recorded. The students from the treatment group were taught the Hooke's Law topic using the integration of investigative experiments and the control group learners were taught using the conventional methods. The same test was given to both groups and scores were recorded. Figure 2 is a graphical representation comparing the mean test scores before and after intervention for the two groups.

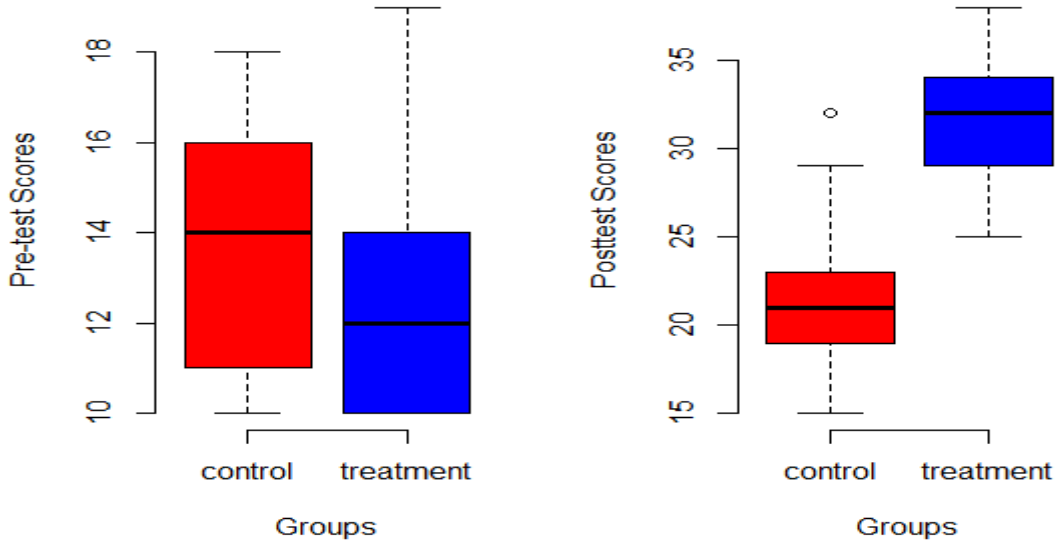

Figure 2: Comparison of test scores for independent groups

Before the treatment, the learners in the control group had a higher mean test score compared to the students in the treatment group. However, after the treatment was administered the treatment group learners performed better than the learners in the control group (Figure 2).

Further explanation of the mean test score differences between the two groups is presented in Table 2. The analysis was done using an unpaired Wilcoxon Rank Sum Test because the data was non-normal requiring the use of a non-parametric method for mean comparison between two groups.

Table 2: Mean Score Test Comparison for Independent Groups

	N	Mean	SD	W	p-value	Decision
Pre-test Physic Scores						
Control Group	58	13.64	2.59	2193.5	0.02801	Reject H0
Treatment Group	62	12.65	2.60			
Post-test Physic Scores						
Control Group	58	21.40	3.49	101.5	2.2*10^-16	Reject H0
Treatment Group	62	31.54	3.32			

The difference in mean test scores between the control and treatment groups before (13.64-12.65) and after (31.54-21.40) the intervention increased from 0.99 to 10.14. Both differences were statistically significant with the scores' difference after the intervention having a higher significance (p=2.2*10^-16). With reference to qualitative Interpretation in Table 1, the findings show that the students in the control group moved from not meeting expectations (34.1%) to meeting expectation (53.5%). On the other hand, the experimental group moved from not meeting expectations (31.62%) to satisfactory (78.85%). The results imply that there was an effect of the investigative instruction in the physics scores resulting in a huge improvement (47.23%) of the scores for the treatment group. Therefore, this study was successful in closing the gap that relates to investigating the effects of Investigative Experiments for the acquisition of SPS in the Kenyan education sector setting.

6.2. Comparison of the Dependent Groups

The mean test scores were analyzed independently for the treatment group and control groups to examine the score differences after using investigative experiments and conventional teaching methods, respectively. Figure 3 is a boxplot that shows the changes in the test scores for the two groups before and after the intervention.

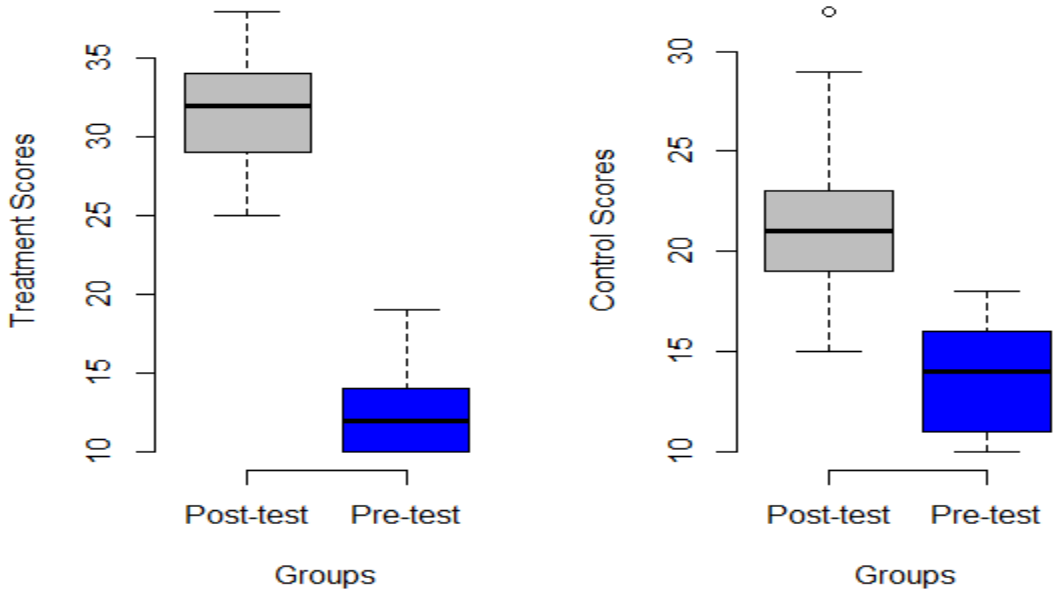

Figure 3: Comparison of test scores for the dependent groups

Students' performance before they were taught Hooke's Law using the conventional method was 14 marks out of 40. However, the scores grew to slightly above 20 after teaching. Similarly, the scores for the treatment group were 15 marks before they were taught. The latter group's mean scores grew to above 30 after the integration of investigative experiments into Hooke's Law topic.

Table 3 explains these differences and their implications. The analysis is done using the Paired Wilcoxon Signed Rank Test which is used when a Paired Sample t-test is unsuitable because of the non-normality of the dataset.

Table 3: Mean Score Test Comparison for Dependent Groups

	N	Mean	SD	V	p-value	Decision
Control Group Scores						
Pre-test	58	13.64	2.59	1035	4.846*10^-19	Reject H0
Post-test	58	21.40	3.49			
Treatment Group Scores						
Pre-test	62	12.65	2.60	3160	9.72*10^-15	Reject H0
Post-test	62	31.54	3.32			

The scores before and after the treatment for both groups improved significantly statistically ($p<0.05$). However, the treatment group improvement before and after intervention (31.54-12.65) was 18.89 compared to an improvement of 7.76 for the control group (21.40-13.64). The disparate differences between the test score improvements between the two groups between the two periods implies that the effects of the investigative experiments teaching on the SPS were higher than for the conventional method. Therefore, integration of investigative experiments in acquisition of science process skills among physics learners was effective.

6.3 Comparison of the Fourfold

Test scores from the four groups show disparities with the pretest scores from the treatment group being the lowest and posttest scores from the treatment group being the highest.

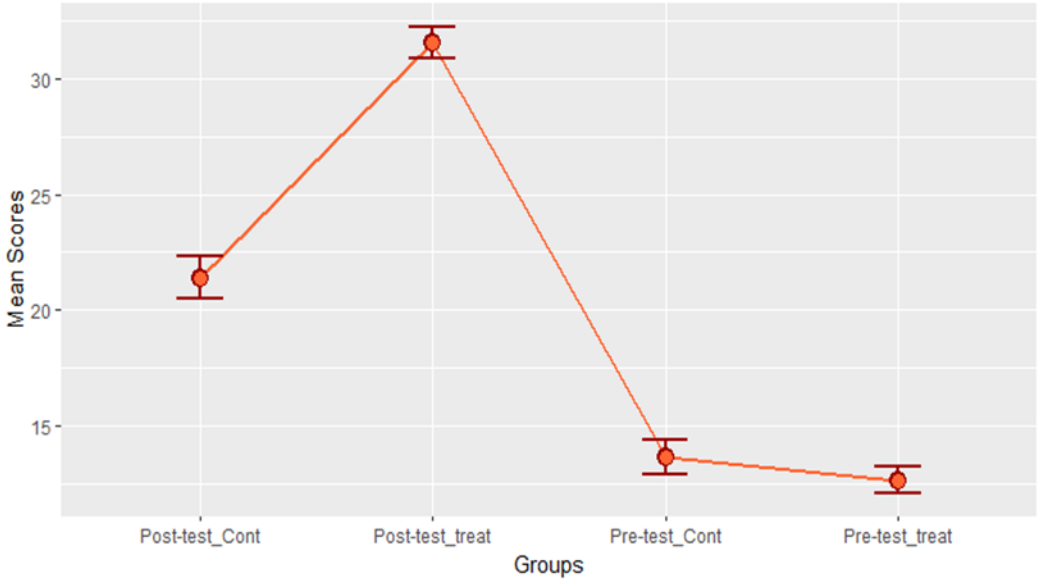

Figure 4: Comparison of the Four Groups

Though there is an improvement in each group as the post-test scores for both groups from the pre-test scores, the treatment group registered the highest improvement where the students moved from not meeting expectations to satisfactory.

Table 4 shows the mean score comparison of the four groups of students. The findings reveal the effect of investigative experiments on the acquisition of SPS. The results are from a Kruskal-Wallis test, a non-parametric version of one-way ANOVA.

Table 4: Comparison of the Pre-test and Post-test Scores for Both Control and Experimental Groups

Groups	Mean	SD	K	Df	P-value	Decision
Pre-test Control	13.64	2.59	204	3	2.2*10^-16	Reject H0
Pre-test Treatment	12.65	2.60				
Post-test Control	21.40	3.49				
Post-test Treatment	31.54	3.32				

The results indicate that at least one of the mean physics scores from the groups was significantly different from the others ($K=204$, $p<0.05$). There was a huge significance in mean differences among the groups as shown by the p-value at a 5% level of significance. The study further conducted a mean comparison between the four groups to find out the group(s) that were different from the others. The comparative analysis was done using the Wilcoxon Rank Sum Test with Continuity.

The results are displayed in Table 5 below.

Table 5: Pairwise Comparison

Groups	**Post-test Control**	**Post-test Treatment**	**Pre-test Control**
Post-test treat	<0.05	-	-
Pre-test Control	<0.05	<0.05	-
Pre-test Treatment	<0.05	<0.05	0.028

The pairwise comparison between the groups indicates that there is a statistically significant difference between all the scores ($p<0.05$). This implies that the conventional teaching method on the topic of Hooke's law had a significant effect on the improvement of the physics scores. There was a moderate statistically significant difference between the pre-test scores from the control group and those from the treatment group ($p=0.028$). However, the post-test scores between the two groups differed significantly.

The findings of the study are in agreement with Ghosh's (2008) study which indicates that teachers' use of an Investigative Science Learning Environment enhances learners' explanation of scientific models, boosts their prediction measurement, and accuracy in observation. Gunnarsson et al., (2018) emphasize that the use of descriptions in physics concepts that require experiments is ineffective and limits learners' understanding of the concepts resulting in poor performance. Brookes et al., (2021) is in harmony with the findings of this study and

indicate that investigative experiment enables learners to enhance their attainment of the science process skills. The experiments enhance learners' understanding of their learning processes by involving them in the entire learning process.

The results of the present study concur with Acharya et al., (2021) who found that teaching topics that require investigative experiments such as magnetic field using conventional teaching methods is ineffective. The study indicated that learners had difficulties understanding the topic's concepts such as the magnetic field patterns and found it abstract. A similar study carried by Ivezić et al., (2019) to investigate the understanding of magnetic field patterns using the same target population using investigative experiments showed that the learners were able to draw and interpret patterns from the magnetic field. The study findings are consistent with the results of the present study which show that investigative experiments have a significant effect in improving science process skills among learners.

7. Conclusion

The finding of the study indicates that the instructional investigative experiment has a significant effect on learners' acquisition of the science process skills. The students in the treatment group had the highest improvement in mean test scores related to the SPS after the administration of the intervention. Application of investigative experiments to teach Hooke's Law topic among the form two learners resulted in a better performance compared to the use of conventional teaching methods. Therefore, the government through the ministry of education should collaborate with relevant stakeholders to promote the integration of investigative experiments into the school curriculum to enhance performance in Physics and other science-related subjects.

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