Enhancing Academic Achievement in Science among High, Medium, and Low Achieving Secondary School Students through Integrated STEM Approach

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Abstract

Globally, there is an increasing search for contemporary instructional approaches, strategies, environment and materials to improve the quality of science and mathematics education. Innovations in science, technology, engineering and mathematics drives the economic prosperity of each nation. Therefore, researchers have advocated for an integrated STEM approach to be entrenched in schools. Consequently, the need to investigate the effects of the integrated STEM approach on students' learning outcomes. In view of this, the study investigated, enhancing academic achievement through to integrated STEM approach among high, medium, and low achieving secondary school students. The study adopted a factorial design 2x3, the sample size is made up of 100 students (experimental 51 and control 49). The experimental group was exposed to a five-phase STEM approach iterative process while the control group was exposed to the conventional teaching method. The instrument for data collection was a genetic achievement test, using the split-half method the instrument was pilot tested and it yielded a reliability coefficient of 0.84. Findings from the study revealed that the integrated STEM approach improves students' academic achievement. It also showed that low achieving students benefited more with the highest mean score, thus, reducing the achievement gap between high, medium, and low achievers. Conclusion and suggestions for further research were highlighted.

Keywords: Integrated STEM approach, Academic achievement, Academic ability levels

Introduction

Global competition and innovation are driven by science, technology, engineering and mathematics. Previous researches reported the need to prepare students efficiently in STEM education in view of its huge relevance to successful living in the 21st century (Corlu, Capraro, & Capraro, 2014; Lynch, Behrend, Burton, & Means, 2013; Mahoney, 2010; NRC, 2011). Similarly, Shahali, Halim, Rasul, Osman, and Zulkifeli (2016), opined that, to remain competitive in the global market, which is dependent on knowledge and innovation, there is the need to raise students' academic achievement in science, mathematics and other associated subjects. In the same vein, it was projected that 15 out of 20 fastest growing profession needs a substantial science or mathematics knowledge and skills (US Department of Labour, 2014). This could be the reason why improving the quality of STEM instruction is one of the most important objectives of most countries. Consequently, for Nigeria to achieve her vision of becoming one of the 20th economies in the world, it must adopt strategies that will enhance meaningful and lifelong learning.

Generally, one of the main aim of education is to enhance students' achievement among others, conversely the observed setback in the process of education in the face of

technology advancement, is that students' academic performance continues to dwindle internationally (Hossain & Robinson, 2012; Saxton et al., 2014). For instance, among 34 countries that participated in the Program for International Student Assessment (PISA), less than one third, scored above the average score in mathematics, science and reading (OECD, 2011).

In Nigeria, educational stakeholders and researchers observed poor academic achievement among Nigerian students in science (Erinosho, 2013; Ofodile & Mankilik, 2015; Yaki & Babagana, 2016). Therefore Nigerian students are not adequately prepared in STEM education to compete in the global market. The dwindling performance among students necessitate the search of an effective instructional approach that would increase student achievement in science.

Comprehensive analysis of developments in science and mathematics education reveals several calls for interdisciplinary instruction in science and mathematics classrooms because it holds the prospects of increasing students' active engagement. In contrast to the passive reception of knowledge by students in the teacher-centred classrooms. Integrated instruction is an approach to instruction that integrate knowledge, principles, and skills from two or more disciplines. In other words, it is explaining a phenomena, exploring a question or solving a problem will be improbable through a single discipline. Jacobs (1989) reported that interdisciplinary teaching and learning helps learners to gain better understanding of the instructional content. STEM education is entrenched in interdisciplinary instruction (Stohlmann, Moore, & Roehrig, 2012).

There is no consensus among researchers on the definition of STEM approach to instruction and the practical way to implement it in the classroom (Blackley & Howell, 2015; Dugger, 2010; Roehrig, Moore, Wang, & Park, 2012). In this study integrated STEM Approach is the integration of knowledge, principles and skills of two or more STEM discipline. The context based integration is adopted; focusing on genetics as a learning content and using appropriate context from engineering (engineering design process) Mathematics (algebraic thinking) while technology is used as a tool for students to explore the learning content.

In addition, Long and Feller (2013) observed that STEM associated intervention will support developing countries to create wealth. Consequently, researchers have advocated for the use of contemporary instructional strategies that are multidisciplinary in nature and learner centred such as an integrated STEM approach. However, there is limited research to ascertain whether the integrated STEM approach to instruction improves students' academic achievement using standardized testing especially in Nigeria. Integrated STEM approach links learning content to a real world experience and it deepens learners understanding of the learning content.

Research studies on the effect of STEM education instruction on students' achievement shows mixed findings; Oliverez (2014) carried out a study to determine the effects on STEM instruction on academic achievement using standardized test in reading science and mathematics among grade 8 students. The group that receives instruction with STEM perform better than the comparative method. Similarly, Thomas (2013) compares students taught with STEM instruction and those taught with traditional method among 4th graders in science, data were collected using standardized testing. The results showed that students who receive STEM instruction perform better than the non-STEM instruction group. Thomas (2013) suggested that the study be replicated on different levels of students.

On the contrary, Tolliver (2016) adopted a causal comparative method to compare students instructed by STEM strategy and students instructed with alternative method in mathematics and reading. The finding shows no significant difference between the STEM instructed group and the non-STEM group. Similarly, James (2014) in his study, found no significant difference between group instructed with STEM and non-STEM group. Further

research in this area will add to existing literatures by considering students' academic abilities (high, medium and low)

Genetic concept is an important aspect of human life, especially in the area of Genetically Modified Food (GMO), cloning, Bioengineering just to mention a few. In spite of its importance, researchers' in several parts of the world have reported learning difficulties in genetics leading to poor performance among student's (Atilla, 2012; Danmole & Lameed, 2014). The reasons advanced for students learning difficulties are the use of the traditional teaching method, genetics are abstract in nature (Atilla, 2012; Danmole & Lameed, 2014). Hence, the need for an integrated STEM approach which will actively engage the learner and encourages exploration through the engineering design process, contrary to the passive nature of a traditional classroom.

Students learning can also be influenced by students' academic abilities. Ability group refers to grouping students' base on their Intelligent Quotient (IQ) or academic achievement and can also be called ability class (high, medium and low). Teachers believe that teaching for deeper understanding is not appropriate for students with low abilities because they may not cope with complex task (Yu, She, & Lee, 2010). Researchers have found that high ability students do perform better than the medium and lower ability students (Gambari, 2010). Contrary to this Yu, She and Lee, (2010) found that an individual ability may not affect his performance, they observed that low achievers perform better than high achievers in a non-traditional approach. Findings from research literature on the effects of ability on student achievement in science has been inconclusive, hence the need to find out how ability levels could influence students' learning using an integrated STEM approach to instruction

Although, research literature in science education is replete with several studies establishing several instructional strategies that enhances students' academic achievement (Krajcik, 2015; Wendell & Rogers, 2013; Yaki & Babagana, 2016). However, STEM education approach is relatively a recent interdisciplinary educational reform with the prospects of enhancing students' academic achievement through students' active exploration and interaction. STEM education is characterized by real world problem solving, active engagement, inquiry, collaboration and has shown that, it is an approach to instruction that enhances students' experience in the classroom (Guzey, Moore, Harwell, & Moreno, 2016; Krajcik, 2015)

The gap in literatures shows that there is scarcity of studies that quantitatively explore the effectiveness of the integrated STEM education approach on senior secondary school students' achievement (James, 2014; Olivarez, 2012; Thomas, 2013). These studies focused on elementary and junior secondary school (4th, 5th and 7th grade). Furthermore, there is limited research linking integrated STEM education and students' academic abilities (High, Medium and Low) and addressing senior secondary school students. Consequently, this study seeks to bridge these gaps in research literatures. The objective of the study is to determine the effects of integrated STEM approach on students' achievement as well as determine the effects of students' ability on their achievement. Hence, the study focus on Enhancing Academic Achievement in Science through Integrated STEM Approach among High, Medium and Low Achieving Secondary School Students.

Research Questions

The following research questions are stated to guide the study;

1. Is there any difference in the main and interaction effects of main treatment between the experimental and control group
2. Is there any difference in genetic achievement among high, medium and low achieving students between the experimental and control group

Research Hypotheses

The following research hypotheses are formulated;

1. There is no significant main and interaction effects of treatment between the experimental and control group
2. There is no significant difference among high, medium and low achieving students of the experimental group

Methodology

The Integrated STEM Approach (ISTEMA) instructional material was developed by the researcher based on the principles of curriculum integration and instructional design as well as the constructivist theory. The elements of ISTEMA include; open ended problem, real world scenario, active engagement and exploration (hands-on and minds-on activities) questioning and inquiry, while the teachers act as facilitator (Frykholm & Glasson 2005; Stohlmann et al., 2012). These elements were carefully selected to provide a learner centred environment, active exploration and enhance deeper understanding. The ISTEMA is a five phase instructional iterative circle adopted from the engineering design process which serve as the instructional context. The phases of Integrated STEM Approach include; Identify problem, information gathering, designing solution, evaluation and re-design and communication of findings. The students are presented with a genetic scenario, the students employ the iterative cycle to explore the problem in the process deepen their understanding of genetics.

Therefore, the instructional goal of this study was for the learners to explore genetics concepts (dominance, recessive, Mendel's first and second laws, genotype and phenotype) and apply the knowledge to design an imaginary organism. The students are expected to highlight the problem the organism will solve, slice gene, sketch the diagram of the animal, construct a 3 dimension of the animal, evaluates and communicate finding to their classmates.

Research Design, Procedures and Data analysis

Factorial design was adopted for this research, to be precise "2 x 3" is used, indicating two independent variables and three levels, which gives a total of six groups. This involves two classes in each class there will be three groups; High, Medium and Low for the experimental and control. The participants of this study are senior secondary school students (average age of 16.5 years) from federal unity schools in Nigeria, stratified random sampling was adopted to select two schools. The schools were randomly assigned to the experimental and control group, the total of one hundred (100) students made up the sample size. Fifty one (51) students in the experimental group while the control had 49 students. The instrument for data collection was a genetic achievement test, made up of forty (40) multiple choice question adapted from West African Examination Council (WAEC) and National Examination Council (NECO).

The instrument was pilot tested using the split-half method, the data collected was analyzed and the reliability coefficient was 0.84 which was considered adequate for this research. The intervention began in the second week after the administration of the pretest in the first week, the intervention lasted for seven weeks. Data generated from pre and post-test were subjected to data analysis based on the stated research questions and formulated hypotheses. Descriptive statistics (mean and standard deviation) and Analysis of Variance (ANCOVA) was employed to analyze the data to answer the research questions and test the research hypotheses

Results and Discussion

Firstly, Pre-test of the genetic achievement test was administered to both groups (experimental and control group) before the commencement of the intervention. The data collected was used to determine the equivalence of the groups and prevent a potential influence on the results.

Table 1
Pre-test Result of Experimental and Control

Variable	N	Df	X	SD	t-value	P	Remarks
Experimental	51	98	30.45	6.39	-2.404*	0.018	Significant
Control	49		33.59	6.66			

*Significant at $p<.05$

Table 1, shows the pre-test result of the experimental group and control group before the intervention, the mean score of the two groups are 30.45 and 33.59 respectively. The calculated t is 2.404 and the p-value is 0.018. This showed that there was a significant difference between the experimental and control group (t= 2.404, p (.018) <.05). The two groups were not equivalent before intervention. Therefore the pre-test score of genetic achievement would be used as covariates to mediate the bias of the initial differences in the two groups

Post-test Result

This section determines the effect of intervention by comparing the post-test data of experimental and control, in other word to compare the effect of integrated STEM approach and traditional teaching method.

The assumption of normal distribution was investigated between the experimental and control groups using statistics and graphical representation. The statistical method adopted to check normality was the Kolmogorov-Smirnov and Shapiro-Wilk test and the result is as *presented in Table 2*

Table 2
Kolmogorov-Smirnov and Shapiro-Wilk Test for Normality

Groups	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	Df	Sig.
Experimental	.107	51	.200*	.978	51	.447
Control	.102	49	.200*	.976	49	.409

Table 2 display the normality test result where; the Kolmogorov-Smirnov and Shapiro-Wilk for the experimental group was p (.200) = >.05 and p (.447) = >.05 respectively. While the control group result for the two test is p (.200) = >.05 and p (.409) = >.05 respectively. Hence, it shows that the data were normally distributed for both experimental and control group. The result was further substantiated with histograms as presented below in figure 1a and 1b.

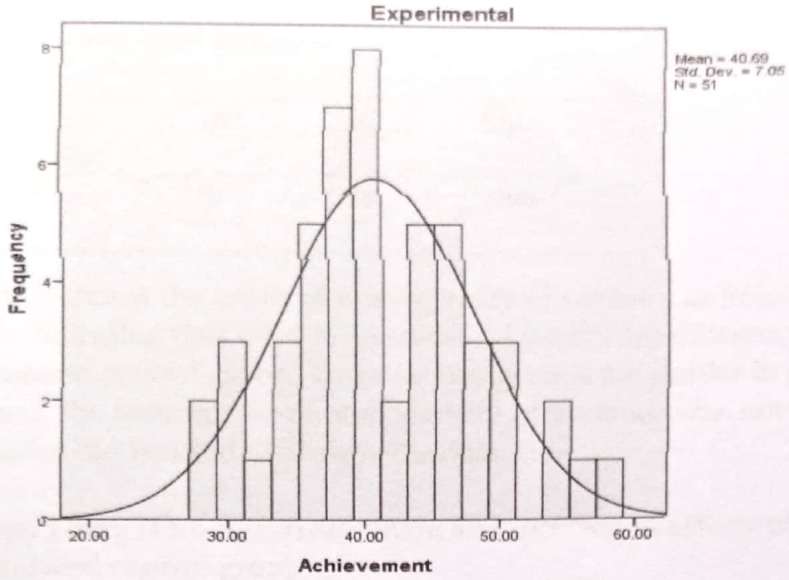


Figure 1a. Histogram of normality for experimental group.

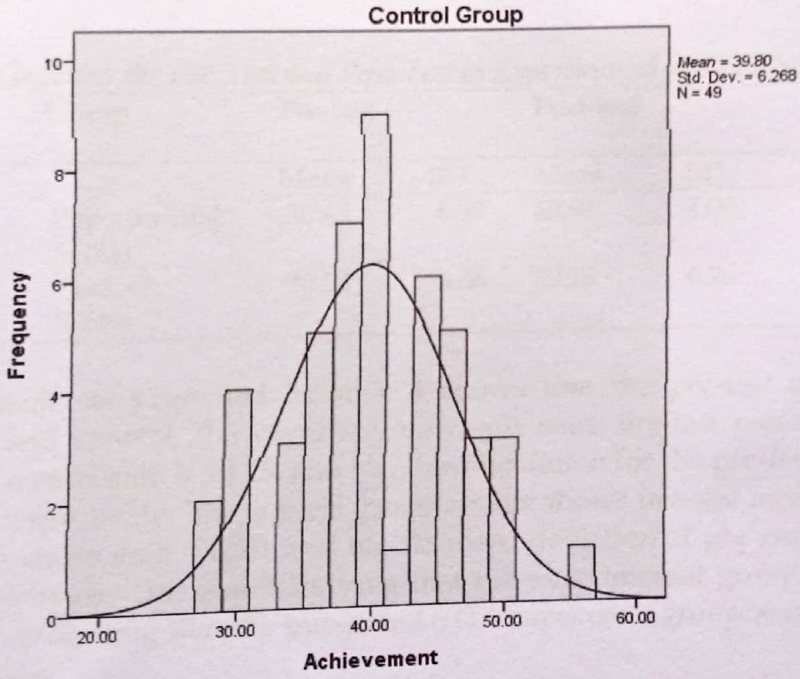


Figure 1b. Histogram of normality for control group.

In view of the numerical and graphical representation it can be concluded that the data was approximately normally distributed, therefore, parametric statistics was employed to analyse the data.

Furthermore, the researcher checked for the homogeneity of variance for genetic achievement score for experimental and control group using Levene's test before applying the factorial ANCOVA test. The result is as presented in table 3.

Table 3
Levene's Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Genetic Achievement	.695	1	98	.406

The table 3 shows the result of homogeneity of variance as follows; F (1, 98) = 0.695, p= (0.406) > .05, indicating that there is no statistical significant difference in the variances of the experimental and control group. Thus the two groups are similar in genetic achievement pre-test score and the assumption of homogeneity of variance was not violated. Therefore, inferential statistics can be used to analyse the data.

Hypothesis One: There is no significant main and interaction effects of treatment between the experimental and control group

The researcher first determines the mean gain within the groups and between the pre-test and post-test as presented in Table 4

Table 4
The Mean Gain between the Pre-Test and Post-Test of Experimental and Control Group

Genetic Achievement	Group	Pre-test		Post-test		Mean Difference
		Mean	SD	Mean	SD	
Overall	Experimental N (51)	30.45	6.39	40.68	7.04	10.23
	Control N (49)	33.59	6.66	39.79	6.26	6.20

The result, as presented in table 4 shows that the pre-test and post-test of the experimental and control, the experimental result were pre-test means = 30.45, post-test means =40.68 means gain = 10.23, and standard deviation for the pre-test and post-test were 6.39 and 7.04 respectively. The control group results shows pre-test means = 33.59, post-test means = 39.79, mean gain = 6.20, and the standard deviation of pre and post-test were 6.66 and 6.26 respectively. This result indicate that the experimental group gain more than the control group, indicating that the integrated STEM approach group was more effective than the control group.

To test the hypothesis whether there are significant main effects of treatment between students' exposed to integrated STEM education and traditional teaching method, a 2x3 between subjects ANCOVA was carried out to determine the main effects and interaction effects between the independent variables. The result is as presented in table 5

Table 5
ANCOVA Results of the Main Effects and Interaction Effects

Tests of Between-Subjects Effects

Dependent Variable: Achievement Score

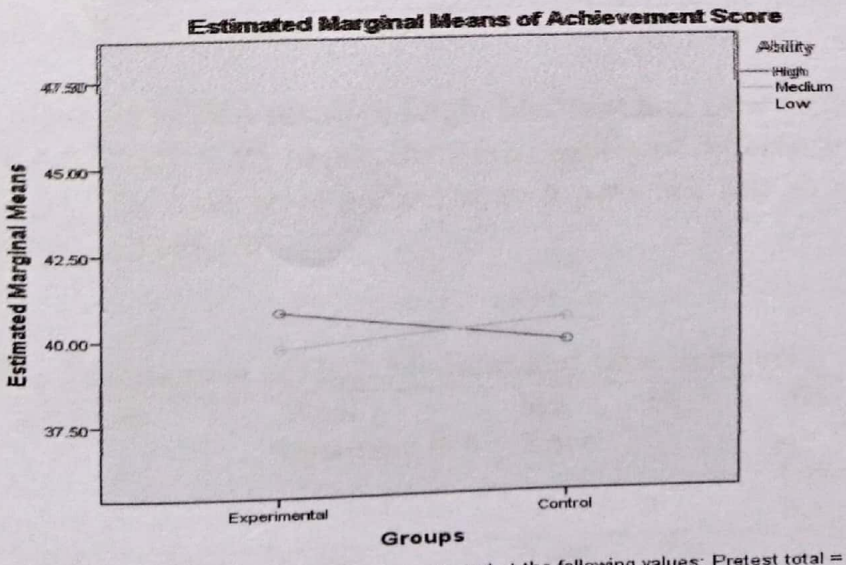
Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	664.831[a]	6	110.805	2.766	.016	.151
Intercept	3738.247	1	3738.247	93.308	.000	.501
Pre-test	142.853	1	142.853	3.566	.062	.037
Group	224.038	1	224.038	5.592	.020	.057
Ability	30.105	2	15.052	.376	.688	.008
Group * Ability	409.107	2	204.553	5.106	.008	.099
Error	3725.919	93	40.064			
Total	166397.000	100				
Corrected Total	4390.750	99				

a. R Squared = .151 (Adjusted R Squared = .097)

Table 5 shows the main effects of treatment on students' achievement in genetics (Group) F (1, 93) = 5.592, p (0.020) < 0.05. The estimated mean of the experimental (42.32) was higher than the control (39.20) indicating students taught with ISTEMA had higher scores than students taught with traditional method. The partial n^2 = .057, indicating 5.7% of the total variance was due the effect of instructional strategies.

The main effect of students' academic ability was not significant F (2, 93) = .376, P (0.688) = >0.05, partial n2 = 0.08, showing that students' academic ability contributed 0.8% to the total variance. There was a significant interaction effect between the independent variable f (2, 94) = 5.651, p (.008) < 0.05, the estimated mean of the experimental group (42.30) was higher than the control (38.89) indicating that the effects of instructional strategy and ability was greater for the experimental group than the comparative group.

This can be illustrated in a graph showing the achievement scores for groups and students' ability in the post-test as presented below



Covariates appearing in the model are evaluated at the following values: Pretest total = 31.9900

From the graph it can be seen that the significant interaction was as a result of the low achievers of the experimental which have the highest mean. Consequently, ISTEMA is effective in enhancing students' academic achievement, especially for low achievers

Hypothesis two, there is no significant difference among high, medium and low achieving students of the experimental group

First, the descriptive statistics of high, medium and low achievers was as presented in table 6

Table 6

Mean and Standard of High, Medium and Low

	N	Mean	Std. Deviation
High	10	42.2000	7.42069
Medium	33	39.0303	6.32201
Low	8	45.6250	7.57699
Total	51	40.6863	7.04979

The post-test score means and standard deviation of high, medium and low achievers were 42.20, 39.03 and 45.62, the corresponding standard deviation were 7.42, 6.32 and 7.57 respectively. The low achievers has a higher mean (45.62) compare to the high and medium achievers. Indicating that, the integrated STEM approach intervention was more effective for the lower achievers. To check whether the mean difference between high, medium and low achievers was significant parametric statistics was employed.

Therefore, to test for this hypothesis two, Analysis of Variance was used and the result is as presented in Table 7a

Table 7a

ANOVA Result of High, Medium and Low Ability Students of Experimental Group

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	348.411[a]	2	174.205	3.914	.027	.140
Intercept	63156.310	1	63156.310	1418.864	.000	.967
Group	348.411	2	174.205	3.914	.027	.140
Error	2136.570	48	44.512			
Total	86909.000	51				
Corrected Total	2484.980	50				

a. R Squared = .140 (Adjusted R Squared = .104)

Table 6 shows ANOVA result of High, Medium and Low achievers, the data yielded an $f(2, 48) = 3.914$, $P(0.027) > .05$, hence, there is a significant difference between high medium and low achievers. The data were subjected to a post hoc test to establish the source of difference as shown in Table 7b

Table 7b

Scheffe's Post hoc Comparison of High Medium and Low Achievers

(I) Ability	(J) Ability	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
High Ability	Medium Ability	2.670	2.408	.273	-2.173	7.512
	Low Ability	-4.550	3.165	.157	-10.913	1.813

Medium Ability	High Ability	-2.670	2.408	.273	-7.512	2.173
	Low Ability	-7.220*	2.629	.008	-12.506	-1.933
Low Ability	High Ability	4.550	3.165	.157	-1.813	10.913
	Medium Ability	7.220*	2.629	.008	1.933	12.506

*. The mean difference is significant at the .05 level. Based on the marginal means

Table 7b shows that the significant difference was between medium ability and high ability with the highest mean difference of 7.22 in favour of the lower ability students. Therefore the hypothesis was rejected. It is important to note that there is no significant difference between high ability students and low ability students indicating that the achievement gap between them was minimized.

Discussion of Results

The study seeks to determine the effects of integrated STEM approach Enhancing Academic Achievement in science through Integrated STEM Approach among High, Medium and Low Achieving Secondary School Students.

The finding shows that there is a significant main effect of treatment on the experimental and control groups, indicating that the experimental group perform better than the control group, that is to say that the integrated STEM approach was more effective in enhancing the learning of genetics among the population of the study. This result agrees with the earlier findings of (Olivarez, 2012; Sahin, Ayar, & Adiguzel, 2014; Thomas, 2013) who reported increased in students achievement when students were instructed with STEM education based approaches. The positive result in this study could be attributed to students' active participation through hands-on and minds-on activities and collaboration among others. With regards to the students' academic abilities there was a significant difference in favour of low ability students, the mean of lower achievers was higher than high and medium achievers. This finding is in agreement with (Yu et al., 2010) who reported that low achievers perform better than high achievers using non-traditional approaches.

Conclusion

An integrated STEM approach was developed to enhanced students' achievement among high, medium and low achievers. The findings of this study provided some helpful information on integrated STEM approach and students' ability, the approach has the potential to bridge the achievement gap between high, medium and low achievers. It also deepens students' understanding leading to increase in genetic achievement. The study also agreed with previous findings on STEM education approach to instruction.

On the overall, this research work provided understanding on classroom practices, especially during the implementation of the integrated STEM based approach to instruction. It clearly shows that instructional environment characterized by STEM elements used in this study will enhance students' achievement and reduce the achievement gap between high, medium and low achievers.

A similar study can be carried out on students in different classes to consolidate on these findings. The integrated STEM approach can also be implemented with other moderating variable such as gender and school location. This approach and the instructional guide can be adopted in teaching subjects like Chemistry, Physics and Mathematics.

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