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Enhancing students' achievement in biology using inquiry-based learning in Rwanda

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ABSTRACT

Students in secondary schools in Rwanda manifest difficulties in learning science subjects including biology. Studies revealed that inadequate teaching methods dominated by teacher-centered traditional or conventional educational strategies are some of the factors that cause difficulties in learning, which in turn leads to poor achievements in biology. This study investigated the effect of inquiry-based learning (IBL) using 5Es instructional model (Engage, Explore, Explain, Elaborate and Evaluate) on secondary school students' achievement in biology. There were 231 secondary school students from six schools in Rwanda constituted the sample. A quasi-experimental quantitative approach consisting of pre- and post-tests was used for data collection. Descriptive statistics were used for data analysis. Results indicated that the mean of post test score of experimental groups was higher than the mean of counterparts in control group. Further, t-test and ANCOVA were used for inferential statistics. Findings showed once again significant differences between experimental groups taught with IBL and control group taught with conventional teaching methods. There was no significant effect on gender while a significant difference based on school location was identified. The study recommends educational stakeholders to use the IBL designed by 5Es instructional model at school level to solve problems related to poor performance in biology.

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1. INTRODUCTION

Biology is a core subject in Rwandan education system in ordinary and upper secondary schools [1]. Biology contributes to knowledge acquisition and scientific skills that can help to understand life processes and interactions between humans and environment. Further, biology advances research in medicine, nutrition, and environmental science [2]. Hence, studying biology subject enrich students' knowledge and skills needed in different fields such as agriculture, biotechnology, molecular biology, environmental biology, and ecology among many others [3].

Despite the importance of biology, the level of students' achievement in biology subject at secondary school in developing countries remains low [4]. Researches revealed that inadequate teaching methods, coupled with students' attitude, nature of topics, students' learning and studying habits, and lack of teaching resources are among the factors that cause poor achievements [4]–[7]. In Rwanda, the problem of poor performance has been identified in a recent study [8]. Some of the causes of poor performance are common to developing countries, while some others are specific to Rwanda as it has been revealed by the authors. They mainly include inadequate teaching methods used by teachers, insufficient resources, and overloaded content which does not correspond to the time allocated to the subject content. In all these cases, the end results is poor achievements as it was indicated by different studies [5], [6].

Further, poor understanding of subject content, might hinder students to attain the 21st century targets in science and technology specifically those aiming to improve human welfare [9]. Quality education is considered as a stand ground to influence socio-economic development providing skills, values and knowledge needed for sustainable future [10]. In this regard, competence-based curriculum (CBC) was developed in some developing countries in sub-Saharan African (SSA), namely Rwanda, Tanzania, Ethiopia, Zambia, and South Africa. The purpose was to boost the learner centered methods and produce graduates with desired skills and competences enabling them to compete on the labor market [11].

In Rwanda, considerable efforts have been put into place to improve the quality of teaching and learning. These efforts include the review and development of new curriculum, improvements of teacher education, preservice teacher training and in-service continuous professional development [1]. The main purpose of trainings was to shift from traditional lecture based-pedagogy to learner-centered method. Despite these efforts, studies revealed that teachers in Rwandan secondary schools did not well implement competence based curriculum and still use inappropriate teaching approaches that did not reflect learn-centered method [12], [13]. This has a negative impact on students' achievement due to the lack of desired knowledge, skills, values and attitudes [8], [14].

In relation with teaching, science education principles consider active participation of students in teaching and learning processes instead of passive education where teacher is taking the main role [15]. In this perspective the inquiry-based learning (IBL) was pointed out as one of instructional approaches that may contribute to the achievements of active teaching and learning methods [13]. Under the IBL, students get involved in finding solutions to the problems presented through questions, propose possible ways of solutions, and communicate results. The IBL is a form of active learning approach whereby students learn from questions or problems, basing on existing experiences or knowledge [16].

IBL is grounded in constructivism premise, where learners take initiative to construct their own knowledge and teacher plays a role as a facilitator [15]. The constructivism as a learning theory as concerned, gives an opportunity to learners to freely use available resources together with their past experience and prior knowledge to solve problems [17]. The epistemology emphasize that learning is active in which learners make sense of new knowledge while associating to their old experiences [18]. For this reason, teachers must consider learners' prior knowledge and provide assistance to practice. This study grounded in socio-constructivism view, elucidate that students build their own knowledge from interaction of their peers [19], [20]. The social constructivist assert that knowledge construction occurs firstly in social context and integrate individually. To sum up, meaningful learning takes place upon collaborations [18].

In the process of the IBL, the 5Es instructional model assists in constructing an inquiry-based instruction. The model includes five specific stages: Engage, Explore, Explain, Elaborate and Evaluate (5Es) [21], that are logically connected. The 5Es instructional model was designed to stimulate observation, questioning and thinking of leaners. It is based on current understanding of learning processes and has been widely used and tested [22]. The 5Es learning cycle was appreciated to provide a room for students to hands on activities and investigation, exploring the nature which help them to grasp knowledge and learn in transferable way and hence be able to apply gained skills in everyday life [23], [24]. Table 1 shows the role of teachers and student in inquiry–based instruction specifically under 5Es instructional model. In each stage of 5Es cycle teacher' and student' activities are specified.

Further, gender in science has been a concern raising attention to research in education. It is an important factor that influences students' interest and attitude towards learning science. The effect of inquiry-based learning on gender in science have been investigated in different studies. Researchers revealed that inquiry approaches did not display a significance difference achievement and metacognition skills in biology between male and female students [25], [26]. Inquiry approach as one of active learning methods was found to reduce gender differences in performance by the fact that male and female students collaborate in groups [27]. With nuance, Hadjichambis *et al.* [25] observed significance differences between female and male in achievement and motivation in biology upon inquiry method in favour of female. Apart from achievement, gender difference in attitude and perceptions was observed in science education.

Table 1. Role of teachers and learners during the stages of 5Es instructional model [28]

Stage	Teachers' activity	Leaners' activity
Engage	Assessing prior knowledge of students through questioning, presentation of the problem, experiment, and any other activity susceptible to excite learners. Teachers formulate the key question based on the lesson objectives	Answering questions asked by the teacher, reasoning to provide the feedback to the problem presented by the teacher, perform the short experiment, and ask questions. They work together with the teacher to formulate the key question.
Explore	Provision of resources for the learning experiment and activities which elicit students' prior concepts and skills	Learners collaborate in groups, use resources, and share ideas to carry out the activities given to them; new knowledge is constructed
Explain	Giving clear explanations after getting the feedback and understanding or views from students in the exploration phase. They answer the key question	Learners explain their views about the activity or experiment given to them
Elaborate	Giving supplementary activities for a deeper understanding of the studied concept. This allows students to deeply understand and answer the key question.	Application of new knowledge and knowledge extension in another situation different from the one they explored in the exploration phase. They deeply understand and answer the key question
Evaluate	Assessing new knowledge and skills, and put an emphasis on the objective of the lesson	Personal or peer assessment

Linking biology subject with teaching methods, performance and gender, studies have been conducted on 5Es instructional model under IBL on secondary students and undergraduate students in biology subject [29]–[31]. Few studies investigated the effect of inquiry-based learning on secondary school students' achievement in biology at upper school secondary level in Rwanda. Furthermore, few research if not any have not yet investigated the effect of inquiry model in biology at secondary school level and make a focus on knowledge, understanding, skills and attitude learning objectives. Students' achievement relating to school location was not highlighted. Besides that, studies on IBL with large sample size were scarce. This study shows the role of active teaching and learning methods by using 5Es instructional model to improve teaching and learning science subjects to provide meaningful learning and assist implementation of CBC. The article gives an insight on how adopting active learning can assist educators to implement appropriate teaching strategies recommended in science education, for instance IBL by using 5Es instructional model.

This study aims to investigate the effect of 5Es instructional model on students' achievement in biology at upper secondary level and provide assistance on the implementation of CBC since studies have witnessed incapability of teachers to confidently implement the new curriculum. This study seeks to answer the following questions: i) What is the effect of 5Es instructional model on students' achievement in biology at upper secondary school level?; ii) Is there any statistical effect of 5Es instructional model on students' achievement of biology among male and female students?; iii) Is there any statistical effect of 5Es instructional model on students' achievement of biology based on the school location?

2. RESEARCH METHOD

2.1. Research design

A quasi-experimental design consisting of pre-and post-tests was adopted where students randomly were assigned to either experimental or control groups [4]. Table 2 displays how the treatment was administered to all groups. Control group was subjected to conventional teaching methods (CTM), whereas experimental group was taught with IBL designed by 5Es instructional model [32]. Pre-test was administered before intervention to check the ability of students whereas post-test was given after intervention to assess the treatment effects.

Table 2. Pre and post non- equivalent quasi-experimental design [33]

Groups	Pre-Test	Intervention	Post-Test
Control	O_1	Io	O3
Experimental	O_2	I	O4

O: output of pre and post-test,
I: intervention using the 5E model,
Io: Conventional teaching methods

2.2. Sampling procedure and sample

In the study, a sample of 231 students was drawn from six secondary schools located in Southern Province and Kigali City in Rwanda. A total of six schools (four from two districts in Southern Province and two from one district in Kigali city) were selected using purposive sampling technique based on good standards in teaching and learning materials and having mathematic, chemistry and biology (MCB) combination at senior four upper secondary school level. In each district one school was randomly assigned to experimental group and the second was randomly assigned to control group. As a results, three schools composed of 118 students made experimental group while three schools composed of 113 students made a control group. Among the participants 112 were female and 119 were male students.

2.3. Instrumentation

Biology achievement test (BAT) was developed focusing on knowledge, understanding, skills, attitude, and values [34]. Items were drawn from biology syllabus of Rwanda at upper secondary school level and biology textbooks provided by CBC at the unit of microbiology [1]. About 30 multiple choice questions were developed subjected to content validity by three experts in teaching biology at the University of Rwanda, College of Education, and three biology teachers at secondary school level. The purpose of validation was to find out if questions are well formulated, adapted to the level of leaners, and relevant. An impartation on wrong formulated questions was given and items were revised. A pilot study was conducted to students in one school in Kigali city and one school in southern province outside the sample but having similar characteristics with sample schools. After piloting, two questions were removed as some students misunderstood the questions and did not respond well. As a result, 28 questions were kept for the study and reflect Bloom taxonomy's cognitive domains. A Pearson reliability of 0.5 coefficient was obtained, hence the instrument was found reliable and worthy to be used [35].

2.4. Data collection procedures

The University of Rwanda, College of Education (UR-CE) offered an ethical clearance for the study and authorities in charge of Education in respective districts gave the permission to conduct the research. Participants were explained the purpose of the study and signed a consent form prior to data collection. Further, schools were randomly assigned to experimental and control groups, where the intact class participated in the study. Three teachers of the experimental groups were trained about the use of 5Es instructional model in three consecutive days while three teachers from the control group were explained the purpose of the study and instructions.

Lesson plans were prepared by the researchers for the sake of not diverging from the focus of the study. An observation checklist was used to record behavior observed during data collection [36]. In this study, the checklist was used to see if all aspects of inquiry learning cycle, the 5Es instructional model (Engage, Explore, Explain, Elaborate and Evaluate) was followed in the lesson. It was made of the commonly used rating Likert scale: SA=Strongly Agree, A=Agree, U=Undecided, D=Disagree, SD=Strongly Disagree. A total of 24 lessons were observed: 6 lessons before the intervention (one per each class), and 18 lessons during the intervention (three per each class).

Before the intervention, pre-test was administered to both control and experimental groups to make a baseline. After, the training about the use of IBL focusing on 5Es model was given to teachers teaching the experimental group while those teaching control students went through conventional teaching method. All groups of students were taught with their respective teachers. Later, post-tests were administered to evaluate the effect of the training. From marking point of view, for each question one mark was given to letter of correct answer and 0 to the letter of wrong answer. Finally, the total marks were calculated on percentage. The passing mark was set to 50%. The effect of intervention was measured at 0.05 level using analysis of covariance (ANCOVA). The P value greater than 0.05 indicated absence of significance difference between two groups while the P value below 0.05 imparted significance difference among compared groups.

3. RESULTS AND DISCUSSION

In this study all scores from pre- and post-tests were summed and computed using excel 16 for descriptive statistics and t-test, while statistical package for social science (SPSS) version 23.0 was used for further statistical analysis. To answer first research question, pre-test scores of all groups were gathered and calculated, the mean score for experimental was found as 47.43% with 8.40 standard deviation and the mean of 47.18% with 9.5 standard deviation was found for their counterpart. Furthermore, a t-test was calculated at 0.05 significant level, a P value of 0.86 ($P>0.05$) was found and shown no statistical significance difference between two groups. This implies that both groups were at the same level before intervention. From the results, on the side of experimental group sixty-three students passed the test and 55 failed the test. On the other hand, 54 students passed the test and 59 failed. To check the impact of intervention between experimental group and control group, descriptive results of post-test show a mean difference of 13.49% against control group. All students (100%, N=118) in experimental group have got above 50% scores in post-test, while in control group, 90 (80%, N=90) passed the post-test and 23 (20%, N=23) still failed the test.

Table 3 shows descriptive statistics of pre-test scores and post-test scores of experimental and control groups based on treatment each group went through. There was a slight difference of pre-test mean scores in favor of experimental group. After treatment, a mean gain of 26.18% was identified on the side of experimental group. On the other hand, a mean gain of 12.94% was highlighted.

Table 3. Pre-test and post-test mean and standard deviation (SD) based on treatment

Group	Pre- test			Post-test		Mean Gain
	N	Mean	SD	Mean	SD	
Experimental /5Es	118	47.43	8.40	73.61	10.652	26.18
Control /CTM	119	47.18	9.5	60.12	11.171	12.94

Table 4 indicates further inferential results, analysis of covariance (ANCOVA) at 0.05 level was computed. The analysis of covariance at ($F=99.625$, $df=1$, $P<0.05$) revealed a significant difference in post-test mean scores of experimental and control groups. Results from mean gain and ANCOVA bear witness that there is a significant difference between mean of post-test scores in favor of experimental group. This indicates that the achievement of students in biology greatly improves with 5Es instructional model.

Table 4. ANCOVA results from achievement test between experimental and control groups

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	14116.075[a]	2	7058.037	68.087	.000
Intercept	16728.197	1	16728.197	161.373	.000
Pretest	3617.447	1	3617.447	34.897	.000
Group	10327.314	1	10327.314	99.625	.000
Error	23634.886	228	103.662		
Total	1075112.000	231			
Corrected Total	37750.961	230			

a. R Squared=.374 (Adjusted R Squared=.368)

Thanks to results obtained from descriptive statistics and inferential statistics, the study revealed a significant difference in biology achievement between students taught with inquiry-based learning under 5Es instructional model and students taught with conventional teaching methods. In respect of impact of the intervention, it has been observed that before treatment, experimental and control group was at same level whereby P value of 0.86 was obtained. After intervention, a mean difference of 13.49% and $P>0.05$ was observed. This indicated that the experimental group subjected to 5Es inquiry learning model outperformed their counterparts subjected to conventional teaching methods. This study revealed that 5Es instructional model has boosted the achievement of students. This finding is in agreement with other studies conducted at the same matter [23], [37], [38].

The big difference of mean scores between experimental group and control group may be explained by the opportunity given by inquiry-based teaching method under 5Es instructional model for students to actively participate at each stage of learning. Moreover, they were given chance to construct knowledge upon guidance by teacher and provided teaching resources. This contributes to knowledge integration and students could not forget what they have learned. Further, when it comes to sit for test, achievement increased. This is in consonance with the findings of [39] elucidating that when students are actively engaged in learning with hands on activities, they can easily grasp knowledge and gain lasting knowledge and promote success. The study observed a viable interaction between students during exploration and elaboration phases on the side of experimental classes. Social interactions were encouraged, where all groups of students were active and collaborative each other to well understand learnt concepts. This is in vein with the study of [40], imparting that social collaboration in learning promote students' deep understanding of concepts and higher order thinking skills which are among factors that robust academic achievement.

Studies identified how using active learning methods play a big role in helping students to understand the subject and grasp knowledge by themselves, as a result their achievements improve [13], [41]. This compiled with the findings of this study, indicating how inquiry learning cycle has helped students to acquire knowledge themselves during interactions with their colleagues and teachers serves as facilitator [32], [42], [43]. The 5Es inquiry model encourages the problem solving atmosphere in cooperative learning in group work for the sake of finding solutions on task given to students, share ideas, think critically and use resources, prior knowledge finding evidence to back up their solution in a given learning experience [44]. This leads to a better understanding of concept, improvement of thinking abilities such as critical and problem-solving skills and improve academic achievement.

Table 5 gives an impartation on the effect of 5Es on students' achievement based on gender after 5Es treatment. The results displayed by ANCOVA at F=.670, df1 and Probability of 0.415 (P>0.05) indicates that there is no significance difference between mean of post test scores between female and male. Females were 58 with a mean score of 73.71% and 60 males with 73.52% respectively. Therefore, the findings portrayed that there is no significant difference in academic achievement in biology between males and females taught with 5Es instructional model.

Table.5. ANCOVA results of experimental group in relation to gender

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1182.660[a]	2	591.330	5.623	.005
Intercept	10404.687	1	10404.687	98.941	.000
Pretest	1181.593	1	1181.593	11.236	.001
Gender	70.458	1	70.458	.670	.415
Error	12093.408	115	105.160		
Total	652654.000	118			
Corrected Total	13276.068	117			

a. R Squared=.089 (Adjusted R Squared=.073)

Regarding gender perspective, this study has identified that there was no significant difference between male and female's test scores after intervention. This implies that, inquiry-based learning under 5Es learning cycle has no effect on gender in relation to students' achievement in biology. This may be explained by the fact that in all groups of students either females or males were equally involved in learning process. All students' activities were performed irrespective of gender. Every student was aware that he or she may be called to present findings from group work in accordance with the activities given by the teacher. This concur with the findings of Hadjichambis *et al.* [25] which identified that IBL has no effect on gender as academic achievement as concerned. We may conclude that the classroom environment instructed by IBL under 5Es learning cycle did not manifest gender disparities in terms of academic achievement in biology.

Table 6 displays the effect of 5Es on achievement based on school location after 5Es intervention. The schools were categorized into three groups, namely rural, sub-urban, and urban respectively. Rural school outperformed all groups with a mean score of 76.98%, the sub-urban scored a mean of 76.59% with slight difference to rural while the urban school scored less with 65.13% mean. The ANCOVA at F=19.07, df=2 results showed a significance difference of P value <0.05 between the mean of posttest scores in relation to school location. This implies that the 5Es instructional model has a significance effect on academic achievement in biology in relation to school location.

Table.6. ANCOVA results of experimental group in relation to school location

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	4162.049[a]	3	1387.350	17.353	.000
Intercept	11337.886	1	11337.886	141.817	.000
Pretest	997.608	1	997.608	12.478	.001
School	3049.846	2	1524.923	19.074	.000
Error	9114.019	114	79.948		
Total	652654.000	118			
Corrected Total	13276.068	117			

a. R Squared=.314 (Adjusted R Squared=.295)

Results from school location imparted that student had a significant difference in achievement in biology. Students in schools located in rural region outperformed those with schools located in sub-urban and urban areas. There was a slight difference of 0.39% between students from rural region and sub-urban in favor of rural students. A big mean difference of 11.85% mean score was identified from rural to urban students. Additionally, sub-urban students outperformed urban students with a mean difference of 11.46%. This finding is in line with the findings of Hadjichambis *et al.* [25] who identified that school location has an influence on students' achievement. The study observed a higher mean score for students in rural area than their counterpart in urban area which is similar to the findings of this study where students from schools located in rural and less urban have a higher mean. Students in urban region manifested poor achievement when compared to other schools. In contrast, Ndihokubwayo, Uwamahoro, and Ndayambaje [45] highlighted that students in urban region have a higher achievement in science subject than students in rural area. This can be associated with less concentration of students in urban areas compared to students in rural areas during their learning.

4. CONCLUSION

Generally, this study confirmed that inquiry-based learning under 5Es instructional model improves students' achievement in biology at secondary level. Findings of the study concerted to justify the impact of intervention, which was greatly observed from the outcomes of students in favor of experimental group with a mean difference of 13.49% to control group. Results confirmed that 5Es has no effect on gender with a slight mean difference of 0.19%, which means female and male students performed equally in biology when subjected to inquiry-based instruction. It was evident that students have significant difference in biology achievement in respect of school location, noting that students from rural and less urban schools performed better than students from urban schools. We recommend further study to investigate the effect of the learning cycle on students' self-efficacy. We recommend the use of 5Es instructional model to assist teachers to implement competence-based curriculum.

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