THE 5E INSTRUCTIONAL MODEL: A CONSTRUCTIVIST APPROACH FOR ENHANCING STUDENTS' LEARNING OUTCOMES IN MATHEMATICS

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Abstract: *The numerous and varied applications of mathematics to all human endeavours justifies placing emphasis on the teaching and learning of the subject. This study established the effectiveness of the 5E instructional model (Bybee, Taylor, Gardner, Scotter, Powell, Westbrook, & Landes, 2006) for enhancing learning outcomes in mathematics. The study adopted a pretest-posttest, quasi-experimental design method. Simple random sampling technique was adopted to select 172 participants (96 males, 76 females, M=15 years) for the study. Four research instruments were used. Data were analyzed using descriptive and independent t-tests. There was no difference in students' achievement and interest in mathematics before treatment. There was a significant posttest effect of treatment on students' mathematics achievement* $t(170) = 4.45$, $p < 0.05$ *and interest* $t(170) = 4.22$, $p < 0.05$. *Teachers are encouraged to adopt constructivist instructional approaches that discourage rote memorization and guide learners to develop their own understanding.*

Keywords: 5E instructional model, constructivism, interest and achievement

Introduction

Mathematics can be referred to as an indispensable element of development, considering its prominent roles in all human endeavours. Its influence justifies making mathematics a core subject across all school grades in countries like Nigeria, beginning in the elementary level. Therefore, priority should be given to the teaching and learning of the subject, especially as students' performance in the subject is yet to reach a satisfactory level (Omotayo, 2017). Analysis of West African Examination Council (WAEC) results showed that less than 50% students received credit level over the past two decades, except in 2008 (Omotayo, 2017).

In Nigeria, previous research studies by Anaduaka and Okafor (2013) indicated that students' poor performance and lack of interest in mathematics could be attributed to inadequate knowledge of some teachers who are charged to teach mathematics irrespective of their background in the subject area. Lack of knowledge may result in teachers being ill prepared to teach math effectively or use specific instructional formats. As a result, some students exhibit poor and faulty foundations in mathematics which leads them to perceive mathematics as a difficult, tedious, boring, and stressful subject. This may be the reason why the WAEC Chief Examiner's Report (WAEC, 2009) suggests that teachers should help students to improve their achievement in mathematics by reducing its abstraction and by removing their apathy and fear of the subject.

According to Odili (2006), many teachers in Nigeria cling to traditional teaching methods where teachers first provide answers to the previous day's homework and then provide direct explanation for new lesson materials. This method of teaching recognizes the teacher as the dominant authority of the class. In this environment, teachers do most of the talking while students only participate when responding to their questions. Students play a passive role, which may not encourage them to develop their own understanding and thinking. Such an approach, according to Salman (2010), is no longer adequate to meet the demands of mathematics education. The approach is teacher-centered and compels teachers to assume more responsibilities than necessary to ensure that students understand what is being taught. This may likely lead to frustration on the part of the teacher, and boredom and lack of interest on the part of the students.

According to Schunk, Pintrich and Meece (2008), students are more likely to engage in academic activities, pay more attention, and demonstrate higher performance if they are interested in a topic or subject. Adeyemo and Kuye (2006) reiterated that there is a very strong connection between interest and effort which implies that the more individuals become interested in a subject, the more effort they will put into their learning. Likewise, Leeherman (2004) believed that teachers are more effective when they incorporate students' interests into lectures. This finding suggests that if students' performance in mathematics is to be improved, emphasis should be placed on instructional strategies that sparks their interest in mathematics.

According to Kurumeh, Achor, Akume, amd Mohammed (2012), many students are not interested in mathematics and what it can offer. In many cases, students tend to fear and dislike the subject. It has been argued that this lack of interest leads to large numbers of failures in annual mathematics examinations in Nigeria (Odili, 2006; WAEC, 2009). Invariably, the students' lack of interest in mathematics has been ascribed to teachers' use of inadequate and monotonous teaching approaches (Usman & Nwabeze, 2011). In order to discourage rote memorization, teachers are encouraged to guide students to develop their own understanding rather than teaching them only about the procedures involved in calculations. That is, students must be fully involved in the teaching and learning processes. This can be achieved by engaging them with activities through which they can explore ideas and methods which can be elaborated through teachers' guidance. Such ideas and methods are embedded in the *Engage, Explore, Explain, Elaborate, Evaluate (5E) Instructional Model* (Bybee et al., 2006).

The 5E instructional Model

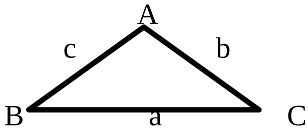
According to Llewellyn (2007), the 5E instructional model can help students move from understanding concrete experiences to the application of principles. The model provides students with opportunities to deeply and meaningfully recall what they already know (see Table 1). According to Ergin, Kanli, and Ünsal (2008), the 5E instructional model is considered one of the best approaches recommended for teaching within a constructivist learning approach. The 5E instructional model is derived from the Atkin and Karplus learning cycle proposed in the early 1960s that was incorporated into the Science Curriculum Improvement Study (SCIS) program (Bybee et al., 2006). According to the same source, the SCIS learning cycle model consists of three stages: exploration, invention and discovery. The Biological Science Curriculum Study (BSCS) 5E instructional model incorporates two additional phases to the SCIS program: engagement and evaluation (Bybee et al., 2006).

The 5E Instructional Phases

Table 1 outlines the aims of each of the 5E Instructional approaches, describes the teacher's role in each phase, and provides examples of student activities applicable to each phase.

Table 1

5E Instructional Phases: Aims, Teachers' Roles, and Activity Examples

Phase	Aims	Teachers' Role	Activity Examples
Engagement	(i) To create interest in students (ii) To generate curiosity (iii) To assess students' previous knowledge	Teacher asks students to: (i) Draw and label types of triangle (ii) Distinctly differentiate the triangles	(i) Draw and label triangle types (ii) Distinctly differentiate triangle types (iii) Sum angles in triangles
Exploration	(i) To practically link previous knowledge to the present topic/ content (i) To discover new knowledge without direct instruction	(i) Teacher guides students to draw triangles (ii) Teacher guides students to take measurements of sides and angles (iii) Teacher monitors students' work for accuracy	((i) Draw triangle ABC  (ii) Take measurement of their sides and angles. (iii) Divide the size of each side by the sine of its opposite angle $\frac{a}{sinA}, \frac{b}{sinB}, \frac{c}{sinC}$
Explanation	(i) To confirm students' newly acquired knowledge (ii) To clarify misconceptions	(i) Teachers prompt students to provide detailed explanation of findings (ii)Teachers ensure appropriate use of terminology (iii)Teachers correct misconceptions	Explain observations (e.g., same values)
Elaboration	(i) To solidify students' understanding	(i) Teachers guide students to carry out additional activities (ii) Teachers guide students to state Sine rule $\frac{a}{sinA} = \frac{b}{sinB} = \frac{c}{sinC}$	(i) Repeat activities with multiple triangle types (ii) students state Sine rule $\frac{a}{sinA} = \frac{b}{sinB} = \frac{c}{sinC}$ (ii) Link acquired knowledge to real-life example
Evaluation	(i) To reflect upon new learning (ii) To assess students' understanding and progress (ii) To identify areas of difficulty and provide remediation	Provide students with exercises ΔABC, $B = 39^0$, $A = 82^0$ a = 6.73cm. Find c	Students solve exercises

At the engagement stage, the instructional task is identified and introduced to the students. Short activities are used to engage learners in the lesson and to spur their curiosity about learning. These activities also enable teachers to assess learners' previous knowledge, so that connections can be made between past and present learning experiences.

In the exploration stage, students are provided with opportunities to engage with the materials and phenomena. Students work with one another to explore ideas through hands-on activities. Under the guidance of their teachers, students clarify their own understanding of major concepts and skills. The teachers' role at this stage is one of a facilitator who provides materials and guides students' focus and concentration while they use their prior knowledge to compose new ideas, explore questions and possibilities, and design investigations (Bybee et al., 2006).

The explanation phase focuses students' attention on particular aspects of their exploration experiences. This stage provides them with opportunities to demonstrate their conceptual understanding and process skills. Learners explain their understanding of the concept and teachers work to address misconceptions. Teacher explanations guide learners towards a deeper understanding, which is a critical part of this phase (Bybee et al., 2006).

Students are provided with opportunities to enhance their conceptions and make connections between related concepts at the elaboration stage. These connections, in turn, initiate further inquiry and new conceptions. Teachers challenge students' conceptual understanding and skills, and students are provided with new experiences that deepen and broaden their understanding. Students apply their understanding by engaging in additional activities.

Evaluation, the last stage in the process, allows teachers to assess whether students have attained conceptions and knowledge, although evaluation processes could be utilized at any stage. Students are encouraged to assess their understanding and abilities in the evaluation phase and the teachers are to assess students' progress (Bybee, et al., 2006).

Previous research (Bybee et al., 2006; Ergin et al., 2008; Taylor, Van Scotter, & Coulson 2007) has established that use of the 5E instructional model improves students' attitude and achievement in science. According to Tuna and Kacar (2013), use of the 5E instructional model improves students' achievement and assists them retain new learning. As the 5E instructional model was primarily designed and commonly used for teaching science subjects, there is a need to investigate its effectiveness in other subjects, including mathematics.

Theoretical Background

This study was grounded in constructivist theory. The theory emerged as the leading approach to human learning in the 1980s and 1990s as interest in behaviourism and information-processing perspectives waned (Mayer, 1996). According to Rice and Wilson (1999), constructivist theory invites students to construct their own knowledge through exploration, as opposed to the traditional educational model that simply provides students with correct answers or facts. To assert the constructivist method, teachers need to provide students with lessons that they can employ in real world situations. However, it is imperative to note that a constructivist-based instructional approach, if not adequately utilized and implemented by a well-trained teacher, may not yield the desired result. For instance, Alsup and Sprigler (2003) explored the effectiveness of three different approaches with grade 8 mathematics students (i.e., a traditional approach; a reform-based approach, including use of manipulatives; and a combination of the traditional and reform-based approaches). The researchers found that the reform-based method, when used alone, was the least beneficial to students. There were no significant differences between the control group who received more traditional-based instruction and the experimental group who received instruction through hands-on learning and the use of manipulatives. These findings suggest that it is not simply the hands-on aspect of the approach that is effective. Rather, students must be encouraged to actively seek out and make sense of mathematical theories if they are to enhance and solidify their learning.

According to Llewellyn (2007), constructivist learning theory is founded on the premise that individuals search for and construct meaning from the world around them. The theory advocates that knowledge is not independent from learners, but that individuals construct knowledge from their personal experiences. Constructivist approaches are important in the formation of meaningful and complete learning. With the aid of the constructivist approach, students can make connections between subjects by constructing and reconstructing information as they process it in relation to their prior knowledge and experiences (Llewellyn, 2007). The 5E instructional model features all the characteristics epitomised by constructivism theory. The approach maximizes opportunities for learner participation by engaging them with a series of activities that assist them to construct their own understanding. In this way, teachers facilitate and guide students to develop their individual understanding.

Hypothesis

1. HO: There will be no significant effect of treatment (5E instructional model and traditional method) on students' achievement in mathematics.

H1: There will be a significant effect of treatment (5E instructional model and traditional method) on students' achievement in mathematics.

2. HO: There will be no significant effect of treatment (5E instructional model and traditional method) on students' interest in mathematics.

H1: There will be a significant effect of treatment (5E instructional model and traditional method) on students' interest in mathematics

Methodology

Research Design

This study adopted a pretest-posttest quasi-experimental design. Participants were assigned randomly assigned to either an experimental group or control group. Performance differences between the two groups was tested statistically. Figure 1 provides an overview of the pre-test, post-test designed used here.

O_1	X_1	O_2	Experimental Group (5E Instructional Model)
O_1	X_2	O_2	Control Group (Traditional Method)

Notes: O_1 = pretest measure; O_2 = posttest measure; X_1 = 5E instructional model; X_2 = traditional method

Figure 1. Pretest-posttest quasi-experimental design.

Participants

The target population for this study comprised all senior secondary school II students drawn from 155 schools in Ibadan Metropolis, Oyo State of Nigeria. Simple random sampling was used to select two local government areas from the five existing local government areas in Ibadan Metropolis. From each of the local government areas, two schools were selected using simple random sampling, comprising a total of four schools.

The selected schools were randomly assigned to treatment conditions. Simple random sampling was used to select two, senior secondary school level students from each of the selected schools. A total of 172 (96 males and 76 females) students participated in the study. The average age of the students was 15 years.

Instrumentation

The following instruments were used for the study: *Mathematic Achievement Test* (*MAT*), *Mathematics Interest Inventory* (*MII*), and the treatment package (TP).

Mathematics Achievement Test (MAT)

The *MAT* was developed by the researcher. The original version of the test consisted of sixty multiple choice items with four response options (A, B, C, D). Items were generated using the Senior Secondary Education Curriculum for Mathematics (SSII) developed by the Nigerian Education Research and Development Council (NERDC). The content validity of the *MAT* was established through item testing at the first three levels of Bloom's taxonomy of educational objectives (i.e., knowledge, comprehension, application: International Assembly for Collegiate Business Education, 2016). The test items were given to experienced secondary school mathematics teachers for vetting.

Having carried out the corrections, amendments, and suggestions made by the teachers, the items were then pilot tested on sixty, senior secondary school II students from co-educational schools similar to the target samples in order to establish the difficulty and discriminating indices for each item. The difficulty index indicates the level of difficulty of an item, while the discriminating index describes how well an item can differentiate between high and low performing test-takers. Thirty items with difficulty indices between .40 and .60 and discriminating indices .030 and greater were selected for the study. The reliability of the items was established using the Kuder Richardson 20 Formula (KR_{20}) which yielded a reliability coefficient of .79

Mathematics Interest Inventory (*MII*)

The *MII* was adapted from Bakare's (1977) *Vocational Interest Inventory (VII)*. The *MII* consists of two sections: Sections A and B. Section A includes items about participant demographics and Section B consists of 20 Likert-scale items (1=Like very much, 2=Like, 3=Indifferent, 4=Dislike and 5=Dislike very much). The instrument was thereafter pilot tested on sixty students from schools similar to the target samples. The reliability coefficient of the instrument was established using Cronbach Alpha which yielded a value of .92. This finding suggests that the instrument was highly reliable.

Treatment Package (TP)

The treatment package refers to the training manual and the instructional guide provided to the research assistants (mathematics teachers) who participated in the study. Information in the package was consistent with the suggestions and contributions of experienced mathematics teachers as well as experts in the field of research.

Experimental Group: 5E Instructional Model Approach

Two schools were assigned to this condition. Having sought the approval of the school authority to use the schools for the study, the mathematics teachers of those schools who served as research assistants were trained to use the 5E instructional model. Micro teaching was also conducted for the teachers to ensure mastery of the teaching method. The training lasted for two weeks. Students in this group were taught using the 5E instructional model for six weeks. Table 2 describes the instructional guide teachers in the experimental group used for each of the five phases.

Table 2

Instructional Guide for 5E Instructional Model

Stage	Duration	Instructional Guide
Engagement Stage	5 minutes	Introduction of the topic. Guide students to recall their previous knowledge. Link entry behaviour with the new topic. Arouse students' curiosity by asking them questions.
Exploration Stage	20 minutes	Exploration of the new topic through hand-on activities. Demonstration and modeling of concepts. Recording of information. Generating conjectures/ideas/ discoveries.
Explanation Stage	15 minutes	Explanation of conjectures/ideas/discoveries. Classification of misconceptions.
Elaboration Stage	15 minutes	Engaged in additional hand-on activities. Expansion and solidification of concepts.
Evaluation Stage	5 minutes	Reflection on learning. Ask questions. Provide additional exercises.

Control Group: Traditional Approach

Two schools were included in the control group. Teachers in this group used traditional methods to teach the same concepts as those taught in the experimental groups for a period of six weeks. The instructional guide for the control group included: a) guiding students to recall previous knowledge, (b) introduction of the new topic, and (c) gradual presentation of the new topic.

Data Collection

The researchers, having selected the sample schools, met with the administrators and mathematics teachers of those schools to inform them about the study and seek their cooperation. Thereafter, a two-week training session was organized for the research assistants. The training sessions involved how to use the prepared instructional guide. Micro teaching sessions were employed in order to ensure that the research assistants delivered the instructional contents effectively.

A week before the commencement of the treatment, the *MAT* and *MII* were administered to participants (pre-test). After treatment, which lasted for five weeks, *MAT* and *MII* were administered again. Data analysis consisted of descriptive statistics and independent t- test.

Results

Independent samples t-test was conducted to compare the mean scores of students in the two groups before the treatment started. Table 3 shows that there was no significant difference between the mean achievement scores of students in the 5E instructional group (M = 7.52, SD = 2.29) and those in the control group (M= 7.76, SD = 2.64), $t(170) = .64$, $p > 0.05$. This implies that the students were academically equivalent before the treatment.

Table 3
Students' Pre-test Mathematics Achievement

	Treatment	N	M	SD	Std. Error Mean	*t*	df	Sig(2-tailed)
Pre-test	5E	88	7.52	2.289	0.244	.636	170	.536
	Traditional	84	7.76	2.637	0.288			

Table 4 shows that there was a significant effect of treatment on students' achievement in mathematics, $t(170) = 4.45$, $p < 0.05$. The table reveals that the mean scores of students taught with the 5E instructional approach (M = 13.15, SD = 2.36) is higher than those taught with the traditional method (M = 11.32, SD = 3.00). This implies that there was significant effect of treatment on students' achievement in mathematics. Consequently, the null hypothesis, which states that there was no significant effect of treatment on students' achievement in mathematics, was rejected.

Table 4
Students' Post-test Mathematics Achievement

	Treatment	N	M	SD	Std. Error Mean	*t*	df	Sig(2 - tailed)
Post-test	5E Group	88	13.15	2.356	0.251	4.458	170	000
	Traditional	84	11.32	3.003	0.328			

Table 5 shows the mean, standard deviation and independent t-test conducted to compare students' mean interest scores before the treatment. The table reveals that there was no significant difference between the mean interest scores of students in the 5E group (M = 44.06, SD = 9.28) and those in the traditional instruction (control) group (M = 43.33, SD = 9.43), $t(170) = .51$ $p > 0.05$. This implies that the students' interests in mathematics were equivalent before the treatment.

Table 5
Students' Pre-test Interest in Mathematics

	Treatment	N	M	SD	Std. Error Mean	*t*	df	Sig (2 tailed)
Pre-test	5E Group	88	44.0568	9.28273	0.98954			
	Traditional	84	43.3333	9.43377	1.02931	.507	170	.613

Table 6 shows that there was significant effect of treatment on students' interest in mathematics, $t(170) = 4.216$, $p < 0.05$. The mean interest score of students taught with the 5E curriculum (M = 63.09, SD = 8.70) is higher than those taught with the traditional method (M = 55.25, SD = 14.79). This implies that there was significant effect of treatment on students' interest in mathematics. Therefore, the null hypothesis which states that there was no significant effect of treatment on students' interest in mathematics was rejected.

Table 6
Students' Post-tests Interest in Mathematics

	Treatment	N	M	SD	Std. Error Mean	*t*	df	Sig (2tailed)
Post-test	5E Group	88	63.0909	8.6962	0.92702	4.216	170	.000
	Traditional	84	55.25	14.79081	1.61381			

Discussion

The findings of this study revealed that the 5E instructional approach significantly improved students' performance in mathematics relative to their peers who received traditional instruction. This result may be explained by the active participation of students at every stage of the instructional model. That is, in the first phase, students were provided with the learning situation that helped them to link their previous knowledge with new concepts. These new concepts were explored in the second phase which fostered critical thinking. This process helped students to make new discoveries and generate more questions which they answered independently. Students provided explanations in the third stage and later elaborated their knowledge in the fourth stage. Lastly, their knowledge was evaluated during the last stage of the 5E instructional program. At every point in time, students were included in the instructional strategy.

This finding corroborates the conclusions of Balci (2005) who studied Grade 8 students' learning and understanding of photosynthesis and plant respiration. The results showed that the students in the experimental group (5E instructional model) were more successful than their counterparts in the control group. This also supports the findings of Cardak, Dikmenli, and Saritas (2008), who investigated the effects of the 5E instructional model on Grade 6 students' achievement during a science unit on the circulatory system. Cardak et al., (2008) established that students who completed the 5E instructional program demonstrated significantly greater performance scores than their peers.

However, there is also evidence that suggests that constructivist-based instruction may not produce superior learning gains in all instances. For instance, Alsup and Sprigler (2003), McNeil and Jarvin (2007), Ivers and Helton (2016), and White (2012) established that there were no significant differences between students in control groups who received more traditional-based instruction and those in experimental group who received instruction through hands-on learning and use of manipulatives. Moreover, manipulatives can be very challenging to incorporate and potentially ineffective, especially if teachers are not confident in using them. As a result, some teachers may unknowingly be teaching their students mathematical misconceptions through manipulative use. Further information is required about teachers' confidence and beliefs in their mathematical training.

The participants in the 5E instructional group demonstrated greater interest in mathematics than those who received traditional instruction. This may reflect that students were practically involved in the lesson delivery. This finding suggests that when teachers adopt an appropriate instructional strategy, learners' interest in mathematics can be stimulated. The finding corroborates the finding of a study exploring the implementation of geometric construction workshops with junior secondary students in Hong Kong (Leung, 2011). Leung concluded that students enjoyed completing the workshop construction tasks. This finding also supports Allen (2007) who affirmed that students increased their skills and showed more interest and enjoyment when learning was done through the use of manipulatives.

Conclusion and Recommendation

The purpose of this study was to establish the effects of the 5E instructional model on students' learning outcomes in mathematics. The result of the study showed that students' learning outcomes in mathematics can be enhanced using a 5E instructional approach. Teachers are therefore encouraged to be dynamic in their instructional approach. More importantly, they are encouraged to adopt a constructivist instructional strategy that will not just present students with new knowledge, but rather guide them to develop their own understanding of that information. Such instruction is the most likely to engender students' interest and improve their performance.

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