TEACHING MATHEMATICS IN A VOLATILE, UNCERTAIN, COMPLEX AND AMBIGUOUS (VUCA) WORLD: THE USE OF CONCRETE – REPRESENTATIONAL – ABSTRACT INSTRUCTIONAL STRATEGY

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Abstract: *This paper presents the teaching of mathematics in a volatile, uncertain, complex and ambiguous world with the use of concrete – representational – abstract instructional strategy (CRAIS). The CRAIS involves active participation of students in learning. The study adopted the pretest-posttest, control group, quasi experimental design. 191 senior secondary II students from four public schools purposively selected from two local government areas in Ibadan municipality were randomly grouped into one experimental and one control group. The experimental group was exposed to CRAIS and the control to modified conventional teaching strategy for 6 weeks. Instrument used was Students' Mathematics Achievement Test (r = 0.83). Two instructional guides on CRAIS and modified conventional teaching strategy were also used. Data were subjected to analysis of covariance. It was found out that the performance of the students taught with CRAIS improved significantly. Therefore, the teachers of mathematics should learn the use of CRAIS for effective teaching of mathematics.*

Keywords: concrete-representational-abstract instruction, teaching strategy, achievement in mathematics, learning difficulties

Introduction

Volatility, uncertainty, complexity, and ambiguity (VUCA) describes the conditions under which organizations, corporations, and institutions operate in the world today. As there is no predictability for *every* issue that may arise, it becomes necessary to plan for *any* issue that may arise. The VUCA world calls for innovative strategies and processes that can be used to cope in any given situation, and if treated right, the VUCA world can be an opportunity for knowledge workers to learn and develop effective agile and flexible strategies. According to Adamson (2013), VUCA is a way of assessing and providing for the changeability of general situations and events which are completely unpredictable. One of the most important ways that mathematics teachers can interact with the VUCA world is through constant learning and accessing new information and new processes.

Volatility refers to the ease and speed in which a situation can change. The methods of teaching mathematics as well as those for solving mathematics problems change rapidly. Downie and McCartney (2013) argue that the required changes need to be cultural: Teachers need to be given an environment equipped with the necessary materials for teaching mathematics, be given moderate periods to teach for effectiveness, and be made comfortable. Tools and technology must be created to nurture learning environments. The problem of uncertainty of the best methods to adopt in the 21st century world also exists. The mathematics teachers' method of teaching must therefore reflect the balance between teaching skills and mathematics knowledge that is necessary to educate and inspire students. The teaching must meet the needs of individual students and the larger group.

Uncertainty refers to the lack of knowledge that surrounds unforeseen events. The teaching of mathematics is uncertain for the teachers of mathematics have never been sure about what their students understand, whether the misunderstandings come from inadequate content or incomplete understanding of difficult concepts. There is also uncertainty about how the teachers can improve on their own classroom practices because no one can be sure of the teaching approach that will be most successful with a particular group of students. The students and the society believe that mathematics is so complex that it is the most difficult subject and should be avoided. This is due to the teaching of the subject in abstract terms. It lacks clarity in the proof of some theorems and involvement of too many mathematical formulae. Mathematics is ambiguous symbolically, has multiple solutions to a single problem, and has paradigmatic and definitional ambiguities. These issues present the potential for confusion and misunderstanding.

Mathematics is viewed as the basis for science and technology and the tool for achieving scientific and technological development. Mathematics plays important roles in the expression of scientific models while the extensive use of its method is required in observing, collecting information, measuring, hypothesizing, and predicting result of scientific investigation. Furthermore, Olusi and Anolu (2010) identified the importance of mathematics and concluded that without mathematics, there is no science. Cangiano (2008) and Citizendium (2010) reiterated the fact that without modern technology, there is no society. It is prerequisite for advanced training and lifetime career choice. In the 21st century, the era dominated by computers, jobs that contribute to the economy will require workers who are prepared to absorb new ideas, perceive patterns, and solve unconventional problems. Mathematical preparation is a key to leadership in our technological society. Economic necessity and concerns of equity demand revitalization of mathematics education. It is, therefore, vitally important to Nigeria (most likely, all the nations of the world) and each individual, that all students receive a quality education in mathematics.

As important as mathematics is to human activities and development, one would expect that students' learning outcomes would be good. The opposite, however, is the case. Students view mathematics particularly in more abstract forms, as an abstruse and pointless subject to study (Otung, 2001). Mathematics educators carried out research on methods and ways of improving the teaching and learning of mathematics at primary and secondary school levels (Adekoya, 2008; Afolabi, 2010; Akinsola & Ogunleye, 2003; Ugboduma, 2008). In spite of these numerous research studies as well as efforts at the instructional level over the years, the performance of students at the West African Senior Secondary School Certificate Examinations (WASSCE) is yet to improve significantly as students are still performing poorly in the subject. Table 1 illustrates the summary of students' achievement in mathematics over a period of thirteen years from 1999 to 2011.

Table 1

Statistics of Entries and Results in Mathematics 'O' Level at the Senior Secondary School Certificate Examination May/June for Nigeria (1999-2011)

Year	Number of candidates	A1-C6		D7-E8		F9	
		N	%	N	%	N	%
1999	756,680	138098	18.3	212514	28.0	381029	50.4
2000	634,604	208244	32.8	196080	30.9	230280	36.3
2001	1,023,102	373955	36.6	334907	32.7	314240	30.7
2002	908,235	309409	34.1	308369	34.0	290457	32.0
2003	926,212	341928	36.9	331348	35.1	229878	24.8
2004	832,689	287484	34.5	245071	29.4	300134	36.0
2005	1,054,853	402982	38.2	267600	25.4	363055	34.4
2006	1,149,277	472674	41.1	357325	31.1	286,826	25.0
2007	1,249,028	584024	46.3	333,844	26.7	302774	24.2
2008	1,268,213	726398	57.3	302266	23.8	218618	17.2
2009	1,348,528	634382	47.0	344635	25.6	315738	23.4
2010	1,306,535	548065	42.0	363920	27.9	355382	27.2
2011	1,508,965	608866	40.4	474664	31.5	421412	27.9

Table 1 shows that it was only in 2008 that students recorded fairly good results with about 57.3% obtaining credit pass and above in the subject. The percentage pass was as low as 18.3% in 1999 while in years 2000-2005, it revolved around 35%, and in more recent years 2006, 2007, 2009, 2010 and 2011, it revolved around 45%. This trend is poor for a very important subject like mathematics and raises questions on the effectiveness of classroom teaching and instructional strategies adopted.

An investigation into the problems of poor students' achievement in the subject revealed that learning problems in mathematics may be caused by intellectual, physical, social, and emotional factors (Sharma, 1999). Additionally, home and school environments, anxiety due to bad experience from previous schooling, lack of self confidence by students, lack of teachers' consideration for students' various learning styles, inability to connect mathematics concept with their everyday lives, and the teaching strategies used by the teacher may cause poor achievement in mathematics.

Concrete – representational – abstract instructional strategy (CRAIS), which involves active participation of students in learning, provides an organizational structure within which lessons can be designed to effectively help students reach an abstract level of thinking around difficult concepts and content. CRAIS consists of three parts with each part building on the previous instruction to promote student learning and retention, and addressing conceptual knowledge of students (Access Center, 2004).

Concrete: At this stage, teacher begins instruction by modelling each mathematical concept with concrete materials. The students must work together with teacher's guidance, student interactions, repeated teacher demonstrations and explanations, and many opportunities for students to practice and demonstrate mastery of concepts.

Representational: The mathematics concept is modelled at the semi-concrete level which may involve drawing pictures that represent concrete objects.

Abstract: The mathematics concept is modelled at the symbolic level using only numbers, notation, and mathematical symbols.

This strategy has its root in Dale's Cone of Experience that learners retain more information by what they "do" as opposed to what is "heard," "read," or "observed" (Dale, 1969). The author asserted that people generally remember 10% of what they read, 20% of what they hear, 30% of what they see, 50% of what they see and hear, 70% of what they say and write, and 90% of what they do as they perform a task. This implies that action learning techniques result in up to 90% retention. Dale (1969) also emphasized that instructors should design instructional activities that build upon more real-life experiences. Real-life experiences make use of more of human senses, and the more senses used, the greater the chance to learn and remember an event (Dale, 1969).

CRAIS actually refers to a simple concept of teaching mathematics to students with learning difficulties (Butler, Miller, Crehan, Babbitt, & Pierce, 2003). As the Access Center (2004) pointed out, the strategy works well with individual students, in small groups, and with the entire class. CRAIS is also appropriate at both the elementary and secondary levels. The National Council of Teachers of Mathematics (NCTM) recommends that when using the instructional strategy, teachers should make sure that students understand what has been taught at each step before moving instruction to the next stage (Berkas & Pattison, 2007).

CRAIS makes learning real by changing the abstract concepts of mathematics into real objects that can be visualized. Another purpose of teaching through a concrete-to-representation-to-abstract sequence of instruction is to ensure that students truly have a thorough understanding of the mathematics skills they are learning. Akinoso (2011) in the study of factors affecting students' achievement discovered that availability of concrete objects as instructional materials can affect achievement in mathematics. Concrete knowledge involves knowing how to manipulate concrete objects or their representation to solve a problem (Slavin, 2009). Many strategies have been developed, but teachers were not trained to use them.

Girls around the world are not worse at mathematics than boys, though boys are more confident in their mathematics abilities; girls from countries where gender equity is more prevalent are more likely to perform better on mathematics assessment tests (American Psychological Association, 2010). Gender inequality in education has remained a perennial problem of global scope (Bordo, 2001; United Nations Educational Scientific and Cultural Organization [UNESCO], 2003). The poor mathematics performance of students is worsened by gender imbalance leading to the problem which now constitutes a major research focus across the globe (UNESCO).

Akinsola and Tijani (1999) point out that mathematics is not a male dominated subject as claimed by some people, but rather, for both sexes provided they are subjected to the same teaching and learning conditions. Plato denied that there is any systematic difference between men and women with respect to the abilities relevant to guardianship – the capacity to understand reality and make reasonable judgment (Kemerling, 2001). Thus Plato advocated that prospective guardians, both male and female, should receive the same education and be assigned to the same vital functions within the society. In Nigeria, gender-achievement studies found no significant relationship between gender and achievement in number and numeration, algebraic process, and statistics (Abiam & Odok, 2006). They, however, found the existence of a weak significant relationship in geometry and trigonometry. Opolot-Okurot (2005) also found differences in students' attitude towards mathematics based on gender. Due to this inconsistency, contradictions and lack of finding clear trend in gender as it influences students' achievement in mathematics, more investigation is necessary. Therefore, the variable is investigated in terms of its influence on students' achievement in mathematics.

Statement of the Problem

Mathematics play a significant role in this modern age of science and technology, yet students are not performing well in the subject. Available evidence shows that students' poor performance is due to their learning difficulties in the subject which could be ameliorated using strategy which include concrete-representational-abstract instructional strategy which allows active participation of students in learning through cutting and modelling of the concepts. However, the teaching of mathematics at the senior secondary school level in Nigeria has not explored this strategy. This study, therefore, investigated the effect of concrete-representational-abstract instructional strategy on students' achievement in mathematics.

Hypotheses

The following alternative hypotheses were formulated and tested at 0.05 level of significance.

H_1: There is significant main effect of treatment on students' achievement in mathematics.

H_2: There is significant main effect of gender on students' achievement in mathematics.

H_3: There is significant interaction effect of treatment and gender on students' achievement in mathematics.

Scope of the Study

This study covered SS II Mathematics students drawn from four selected senior secondary schools in Oyo State, Nigeria. The study determined the effects of concrete – representational – abstract instructional strategy on achievement in mathematics. It also found the moderating effect of gender on their achievement in mathematics. The contents selected for this study were circles, volume of solids, and angles of elevation and depression. These concepts were listed in West African Examinations Council [WAEC] Chief Examiners' reports of 2004, 2005, 2007, and 2009 as the areas where candidates performed poorly in the senior secondary school mathematics examinations.

Significance of the Study

It was hoped that findings of this study would help teachers to help students develop tangible understandings of mathematics concepts. When students are supported to first develop a concrete level of understanding for any mathematics concepts, the foundation can then be used to later link their conceptual understanding to abstract mathematics learning activities. This would give them confidence in coping with everyday life problems. It was also anticipated that findings from this study would help teachers of mathematics in making the learning of different concepts in mathematics real and reduce the teachers' constraints in teaching and would further improve students' achievement in mathematics. Parents would also benefit from this study in the sense that they would be relieved of the financial burden arising from persistent poor performance of their children and wards in mathematics all the time and the attendant re-enrolment of their students for the examinations. Hence, their resources would be conserved when students do not have to re-register for examinations especially in mathematics. The study is significant to the society in the advancement of science and technology and overall development which cannot be achieved without a sound knowledge of mathematics. Also, the study would provide useful information to mathematics educators, curriculum developers, and government agencies on the introduction of remediation into the programme of mathematics teaching and learning.

Methodology

Design

The study adopted the pretest-posttest, control group, quasi-experimental design. This design is schematically represented as:

E: 0_1 X_1 0_2

C: 0_1 X_2 0_2

0_1 represents pretest for the experimental group and control group. 0_2 represents posttest for the experimental group and control group. X_1 represents CRAIS experimental treatment. X_2 represents the control treatment of modified conventional teaching strategy (MCTS).

Sampling

Two local government areas were selected randomly from the list of the local government areas in Ibadan. Two senior secondary schools were purposively selected from each of the two selected local government areas, making four schools based on two criteria: the school must be public co-educational and the SS II students in the schools must have completed SS I mathematics curriculum at the time of the study. Each local government area selected was randomly assigned to treatment such that the two schools in the local government area were for the same treatment group so that if there is any interaction between teachers in the same local government, it would not affect the study because of the same treatment. Two schools were assigned CRAIS and two were for control.

Instruments

Three instruments used for this study were (a) Instructional Guide on Concrete-Representational-Abstract Instructional Strategy (CRAIS), which is a self-designed guide to teach the students in the experimental group based on the steps listed by the Access Center (2004). (b) Instructional Guide on Modified Conventional Teaching Strategy (MCTS) based on normal ways of writing lesson notes with little adjustments. The teachers in this group were given some steps to follow to ensure uniformity. Prior to use in the study, the instructional guide was given to two senior secondary school mathematics teachers for review and all their suggestions were incorporated in the guide. (c) Students' Mathematics Achievement Test (SMAT) is a forty-five item multiple choice test constructed by the researcher to measure students' cognitive achievement in mathematics. The SMAT has two sections: the first section contained the demographic variables of the students. The second section consists of forty-five multiple choice items on the selected topics in SS II mathematics curriculum. The content covered the following areas: circles, volumes, and angles of elevation and depression. The instrument was validated after which fifteen items were dropped out of initial sixty. The reliability was determined using Kuder-Richardson formula 20 (KR–20). The difficulty levels were computed, and the result of the analysis was used to pick items that were neither too difficult nor too easy. These yielded difficulty indices of between 0.32 and 0.56 with a reliability index of 0.83.

Procedure for Data Collection

The first 2 weeks were used for the training of the research assistants and the mathematics teachers taking part in the study. The researcher was the resource person. Fourteen teachers and two research assistants were trained to ensure that participating teachers adhered strictly to the instructional and experimental procedures. Twelve teachers were trained with CRAIS, but two were selected for the experiment. Two teachers for the control group were asked to use the steps on the instructional procedure on MCTS. The SMAT was administered to the students as pretest. The instructional packages prepared by the researcher were used by the trained teachers to teach the students for six weeks after which the posttest was administered using SMAT.

Method of Data Analysis

Data collected were analyzed using the analysis of covariance (ANCOVA). This was used to test the hypotheses stated. Also, the multiple classification analysis (MCA) aspect of ANCOVA was used to determine the magnitude of the mean scores of the different groups.

Results

H_1**:** There is significant main effect of treatment on students' achievement in mathematics. From Table 2, treatment has significant effect on students' achievement in mathematics ($F_{(1,\ 190)} = 3.31$; $p < .05$). Hypothesis 1 is, therefore, not rejected.

Table 2
ANCOVA of Posttest Achievement Scores

Source	Type III – Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Mod.	918.18	4	229.55	3.34	.01	.07
Intercept	6576.90	1	6576.90	95.59	.00	.34
Pretest	743.16	1	743.16	10.80	.00	.06
Treatment	227.95	1	227.95	3.31	.04*	.02
Sex	40.03	1	40.03	.58	.04	.00
Treatmt x sex	.81	1	.81	.01	.91	.00
Error	12797.01	186	68.80			
Total	92778.00	191				
Corrected total	13715.19	190				

*Significant at $p < .05$

Table 3 shows that students in CRAIS had higher posttest achievement score ($\bar{x}$ = 21.32) than their counterparts in the conventional instruction ($\bar{x}$ = 19.07).

Table 3
Estimated Marginal Means for Treatment and Control Groups

Treatment	Mean	Std. error	95% Confidence Interval	
			Lower Bound	Upper Bound
CRA	21.32	.80	19.74	22.90
Control	19.07	.93	17.25	20.90

Grand Mean = 20.19

H_2: There is significant main effect of gender on students' achievement in mathematics. From Table 4, female students obtained slightly higher achievement mean score ($\bar{x}$ = 20.66) than their male counterparts ($\bar{x}$ = 19.73). Table 2 shows that that gender has no significant effect on students' achievement in mathematics ($F_{(1, 190)} = .58$; $p < .05$). Hence hypothesis 2 is, therefore, rejected.

Table 4
Estimated Marginal Means for Male and Female Students

Sex	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Male	19.73	.85	18.06	21.41
Female	20.66	.87	18.94	22.37

Grand Mean = 20.19

H_3: There is interaction effect of treatment and gender on students' achievement in mathematics. From Tables 2 and 5, the interaction effect of treatment and gender on students' achievement in mathematics is not significant ($F_{(1,\ 190)}$ =.01; p < .05). Therefore, hypothesis 3 is rejected.

Table 5
Estimated Means for Males and Females in Experimental (CRAIS) and Control Groups

Treatment	Sex	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
CRAIS	Male	20.92	1.13	18.69	23.15
	Female	21.72	1.12	19.50	23.93
Control	Male	18.55	1.27	16.05	21.04
	Female	19.60	1.34	16.95	22.25

Grand Mean = 20.19

Discussion

Findings of the study revealed that concrete-representational-abstract instructional strategy was more effective at improving students' achievement in mathematics than the conventional strategy. The effectiveness of the CRAIS over the conventional instructional strategy could be due to the fact that CRAIS is learner-centered which provides learners with the opportunity to participate actively in learning. This high level of involvement of learners enabled them to solve real mathematical problems thereby gaining required knowledge which helped them to make meaning from information presented. This is line with the opinion of Devlin (2000) that hands-on experiences allow students to understand how numerical symbols and abstract equations operate at a concrete level, making the information more meaningful to students. This finding also agrees with the submission of Harrison and Harrison (1986) that the use of concrete materials develops more precise and more comprehensive mental representations. This finding corroborates the earlier findings about CRAIS with that of Witzel, Mercer, and Miller (2003); students taught using the CRA sequence of instruction performed fewer procedural errors in mathematics.

Modified conventional teaching strategy was less effective on students' achievement in mathematics. Several studies in the area of mathematics have shown that instruction, especially at the secondary school level, remains overwhelmingly teacher-centered with greater emphasis being placed on lecturing rather than helping students to think critically across subject areas and applying their knowledge to real-life situation (Butty, 2001). This finding is also in line with Akinsola and Olowojaiye's (2008) finding that the conventional teaching strategy was inadequate for improved students' achievement in mathematics.

The findings on gender show that it has no significant influence on students' achievement in mathematics. Though the female students obtained slightly higher mean achievement score than male students, but the difference was not significant. This study has shown that mathematics is neither a male-dominated nor a female-dominated subject in line with the assumptions of Akinsola and Tijani (1999). This result negates the findings that found significant main effects of gender on students' achievement in favour of boys (Odogwu, 2002; Ojo, 2003). Findings of this study are in line with others who found no significant relationship between gender and achievement in mathematics (Abiam & Odok, 2006; Hyde & Mertz, 2009; Vale, 2009).

Conclusion

Based on the findings, it could be concluded that the CRAIS, when employed in the teaching and learning of mathematics concepts, has great potential for improving both achievement and attitude of every student towards mathematics. Active participation of students in cutting, modeling, and drawing before symbolic representation of the concepts would not only lead to the achievement of the desired objectives of mathematics learning but would develop greater confidence in students, and this will eradicate the problem of mass failure in mathematics and increase enrollment in science-oriented subjects and improve the technological development of the country. In this case, mathematics teachers should make conscious efforts towards learning about the CRAIS and adopting it in their teaching.

Recommendations

In order to improve students' achievement in mathematics, strategies which involves active participation of students' in learning such as the CRAIS should be adopted for teaching mathematics to move teachers away from teaching mathematics in abstract. Training and retraining programmes such as seminars and workshops should be organized by government and professional associations like Science Teachers Association of Nigeria (STAN) and Mathematical Association of Nigeria (MAN) for the teachers of mathematics to learn more about CRAIS to improve and enhance students' achievement in mathematics. Teaching materials are very important in teaching and learning of mathematics as well; therefore, the government should purchase these materials and distribute around the schools to make learning real and increase students' level of assimilation.

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