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Problem – Based Instructional Strategy and Numerical Ability as Determinants of Senior Secondary Achievement in Mathematics

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Abstract
The study investigated Problem – based Instructional Strategy and Numerical ability as determinants of Senior Secondary Achievement in Mathematics. This study used 4 x 2 x 2 non-randomised control group Pre test- Post test Quasi-experimental Factorial design. It consisted of two independent variables (treatment and Numerical ability) and one moderating variable (gender). The subjects consisted of 196 Senior Secondary School Students (SSS II) 90 males and 106 females). A stratified cluster sampling technique used to select the students from four equivalent co-educational Senior Secondary Schools that are distinctly located from each other within the town of Ijebu – Ode, Ogun State. Two valid and reliable instruments (Numerical ability test and Mathematics achievement test) developed to collect data for the study. Their difficulty indices of the items selected ranged from 0.50 – 0.65, discriminating indices of 0.45 – 0.71 and reliability index values were obtained to be 0.76 and 0.83 respectively using Kuder – Richardson ((K R- 20). The results show that the three variables when combined (treatment, numerical ability and gender) jointly accounted for 28.0% of the variation obtained in the students school in mathematics; there is no significant interaction effect on the numerical ability and Gender on students' achievement in mathematics (F (1,196) = 0.242, P > 0.05). And treatments have no significant influence on the students' achievement in mathematics. It is therefore recommended that appropriate courses need be introduced into teacher education programme for the training teachers in these students of designing and developing useful learning packages for mathematics instructions.
Keywords: Problem-based instructional strategy, numerical ability and achievement in mathematics

INTRODUCTION

Mathematics is a compulsory subject at the secondary school level irrespective of students' learning ability. Unfortunately, students are not passing the subject as expected. The consistent poor performance in Mathematics, which our students have shown for nearly a decade, now casts serious doubt on the country's high attainment in science and technology (Abiam, 2005, Adesoji, 1999 & Ale, 1981). The causes of students' under achievement in mathematics are perhaps less obscured than their remedies. Some researchers (Tella, 2007, Adedayo, 2001, and Alio & Paters, 2000) have identified numerous variables that affect the effective teaching and learning of secondary school mathematics in Nigeria. These researchers were of the view that paucity of relevant mathematics textbooks, inadequate instructional materials, shortage of qualified and motivated mathematics teachers, students' population explosion, the abstract and quantitative nature of mathematics, the use of lecture method with its characteristics monologue (teacher talking non-stop) in teaching the subject. Adedayo (1995) noted that the use of lecture method in teaching the subject makes a wide range of boys and girls who have moderate numerical ability to view mathematics as difficult, unimaginative, hard to understand and requiring much memorization and quantitative ability. Some other studies such as Alio (2001); Ifamuyiwa (2001) and Esan (1999) have also indicated that the use of lecture method has most secondary and university mathematics teachers could be responsible for students' under achievement in mathematics as well as the gender differences associated with it. In consequence, the studies recommended a hand on approach to the teaching of the subject, particularly at the secondary school level.

The difficulties and frustrations encountered by these students in learning Mathematics are often blamed on poor methods of teaching. In order to foster and enhance teaching for understanding of the basic concepts in Mathematics, some modern techniques and strategies emerged to meet the students' needs in Mathematics. Such as Direct Instruction (DI) developed by Siegfried Engelmann and Wesley C. Becker (1960), Personalized System of Instruction (PSI) developed by Fred Keller (1968), Learning for Mastery (LFM) developed by Benjamin Bloom (1971), and Problem-based learning (PBL). The major objective of these teaching strategies is to ensure that learners attain mastery of a given task before a new one is introduced.

For the purpose of this study, Problem-based Instruction (PBI) is a student-centered pedagogy in which students learn about a subject through the experience of problem solving (Peters; Amador; & Miles, 2006). Students learn both thinking strategies and domain knowledge. According to Schmidt; Rotgans and Yew (2011), the goals of PBI are to help the students develop flexible knowledge, effective problem solving skills, self-directed learning, effective collaboration skills and intrinsic motivation. PBI is a learner-centered educational method. Using this approach, learners are progressively given more and more responsibility for their own education and become increasingly independent of the teacher for their education. PBI produces independent learners who can continue to learn on their own in life and in their chosen careers. Problem-based instruction (PBI) is an instructional strategy in which students actively resolve complex problems in realistic situations. As an instructional model, it demonstrates that any learning can be accomplished through "learning prompts," which serve both to intrigue the learner and ensure high quality learning outcomes. It can be used to teach individual lessons, units, or even entire curricula. PBI is often approached in a team environment with emphasis on building skills related to consensual decision making, dialogue and discussion, team maintenance, conflict management, and team leadership.

Numerical ability tests are designed to measure the candidates' capacity to manipulate or use numbers to correctly solve problems (Ann, 2004). Such tests According to Ann (2004), it is the ability to relatively solve problems in number sequencing, make accurate mathematical deductions through advanced numerical reasoning, interpret complex data presented in various graphical forms, deduce information and draw logical conclusions. Researchers have established the fact that there is a strong association between numerical ability and performance in Mathematics and Science subjects (Ishola, 2000; Raimi, 2002; Yunker & Krull, 2009; Meyer, 2011). Meyer (2011) reported that achievement in Mathematics and Language arts were related to three abilities – numerical ability, word fluency and memory. Yunker et-al (2009) reported that there is positive effect of numerical ability on performance as strongly significant. Ishola (2000) and Raimi (2002) also affirmed the fact that numerical ability is a good predictor of achievement in Mathematics and Science subjects. In the study carried out by Olatoye and Aderogba (2011) reported that numerical and verbal abilities combined together accounted for about 38.8% of the total variance observed in students' performance in the aptitude test. Thus, for students to perform well in the general aptitude tests, they need to have high numerical and verbal abilities. Amosun (2002) specifically noted that high mathematical ability students performed better than their low ability counterparts in all the dependent measures.

However, Olatoye and Aderogba (2011) reported that there was no significant difference between male and female students' performance in verbal ability, numerical ability and general aptitude tests. In contrast, Falaye (2006) who investigated the influence of gender, course of study and numerical ability on secondary school students' achievement in practical geometry observed that the impact of students' numerical ability on their achievement is not significant across students' gender and course of study. In Ursos and Bauyot (2006) reported that there no significant relationship between numerical ability and achievement. Furthermore, Holloway and Ansari (2009) added that the school mathematics performance of children was found not to be related to the magnitude of their numerical abilities. Alio and Harbor Paters (2000) in his study on gender interaction on achievement discovered that there was a marked difference between the performance of male and female students. Erinosho (2005) and Ogunkola (2006) affirmed that boys performed better than girls in science. However, Tang (1989) found that gender difference is in favour of female students.

The study designed to assess the effects of the Problem-based learning instructional strategy (treatment), Numerical ability and Gender on mathematics.

Hypotheses

Specifically, it sought to provide answers to the following null hypotheses at 0.05 significant levels.

1. there is no significant difference of main effects of: (a) treatment (b) numerical ability (c) gender on mathematics achievement of students.
2. there is no significant interaction effect of:
   (a) treatment and numerical ability;
   (b) treatment and gender
   (c) numerical ability and gender on students' achievement in mathematics

3 there is no significant interaction of treatment, numerical ability and gender on students' achievement in mathematics.

Methods

Research Design: This study used 4 x 2 x 2 non-randomised control group Pre test- Post test Quasi-experimental Factorial design. It consisted of two independent variables and one moderating variable. The variables of the study were:

1. The treatment (Problem-based instructional strategy). It had four levels (PBIS, PBIL, PBIM and TGM).
2. Numerical ability: It had two levels (low and high)
3. Gender: It had two levels (Male and Female)

Sampling technique and Sample

The subjects consisted of 196 Senior Secondary School Students (SSS II) 90 males and 106 females) varied numerical ability groups (84 high and 117 low) and Age (mean age = 15 years, SD = 0.81). A stratified cluster sampling technique used to select the students from four equivalent co-educational Senior Secondary Schools that are distinctly located from each other within the town of Ijebu – Ode, Ogun State, Nigeria.

Instrumentation
Two valid and reliable instruments developed to collect data for the study:

1. **Numerical Ability Test (NAT):** This instrument administered to determine the students' numerical ability levels. It contained 30 multiple choice test items four options letters A – D. The content areas for the instrument covered the numerical reasoning activities. The difficulty indices of the items selected ranged from 0.50 – 0.65 and the discriminating indices of 0.45 – 0.71. 0.76 reliability index obtained using Kuder – Richardson ((K R- 20).
2. **Mathematics Achievement Test (MAT).** It contained 50 multiple-choice items with four options A – D. The difficult indices of the items ranged from 0.48 – 0.70 where the discriminating indices of the items from 0.42 – 0.71. Kuder – Richardson (KR - 20) formula used to ascertain the reliability index of the items and calculated to the 0.83.

Data Analysis: The following steps taken:
Step 1: The mathematics teachers of the participating schools (who trained on how to use the treatment packages and instruments) made the students to respond to two instruments. (Numerical Ability Test (NAT) and Mathematics Achievement Test (MAT)).
Step II: The NAT scores served the purpose of classifying the students into two different ability groups while the MAT scores served as pre-test (co variables) scores.
Step III: After this, the teachers provided the treatment conditions to the three experimental and the control groups (simple random sampling was used to decide the specific treatment provided for each intact class of a selected schools). The study conducted immediately after the school hours so that the schools programmed would not be disturbed and students were given some incentives. The treatment lasted for six weeks. At the end of last week, the teachers administered the MAT and as Post test.
The treatment for the experimental groups was characterised by Problem – based learning activities at three phases:

1. Identification of problems involves, providing learning objectives and work schedule;
2. Students working on the problem: solving, library searching for the solutions in the library or textbooks
3. Individuals or groups presenting findings solution and discussed and after which a summary or conclusion of what has been learned is done (Adapted from: Iroegbu & Okpala, 1998).

These phases were not associated with the treatment for subjects in the control groups:
Experimental Group 1: (PBIS)
The 48 subjects in this group were exposed to problem-based instructional strategy in small groups of four subjects per group. The teacher and students identified the problems involved after which students' exercised control of how to carry out the research.
Experimental Group II (PBIL): The 48 subjects in this group were exposed to problem-based instructional strategy in large groups of 12 subjects per group. The teacher and students identified the problem involved after which the students' exercised control of how to carry out the research.
Experimental Group III (PBIM): The 50 subjects in this group were exposed to a modified PBIL. The modification was such that the teacher identified the problems involved and exercised control of how to carry out the researcher. For example, the teacher prescribes the line of research and assigned tasks and roles to individual members of the small groups.
Control Group Method (TGM): The 50 subjects in these groups were exposed to teacher's guided method of instructions.

Data analysis
The Post Test Mathematics Achievement Scores were subjected to analysis of covariance using Pre test Mathematics scores as covariance.

Results and Discussions

Table 1: Analysis of Covariance (ANCOVA) of main and interaction effects of treatment, numerical ability and gender on students' achievement in mathematics.

Source of Variation	Sum of squares	Df	Mean square	F-ratio	Sign. of F
Co-variates	1230.810	1	1230.810	40.691	0.000*
Main effects	11075.934	1	11075.934	366.177	0.000*
Treatments	3085.735	3	1028.578	34.005	0.000*
Numerical Ability	31.135	1	15.578	22.322	0.000*
Gender	2.343	1	2.343	0.575	0.598
2-way interactions					
Tr x NA	161.634	3	126.939	1.588	0.012*
Tr x Gender	140.819	3	46.940	2.376	0.046*
Gender x NA	14.653	1	7.327	0.242	0.678
3-way interactions					
Tr x NA x Gender	335.838	3	55.973	1.850	0.090
Explained	5591. 532	17	232.981	7.702	0.000*
Residual	7743.365	179	30.248		
Total	13334.897	196			

Where: Tr = Treatment
NA = Numerical Ability
* = Significant level at P < 0.05

Table 2: Multiple Classification Analysis (MCA) of students' achievement mathematics according to treatment, numerical ability and gender.

Grand mean = 16.198

Variable + Category	N	Unadjusted deviation	Eta	Adjusted for indep + con	Beta
Treatment					
1. PBIS	48	4.595		2.859	
2. PBIL	48	1.965		1.092	
3. PBIM	50	-2.150	.303	-1.745	.217
4. TGM	50	-3.100		-2.221	
Numeral ability					
1. Low	112	-4.368		-5.557	
2. High	84	2.158	.328	2.745	.417
Gender					
1. Male	90	-1.516		-2.826	
2. Female	106	1.902	.181	3.545	.338

Multi R square = 0.280
Multi R . = 0.529

Research Question 1: Is there any significant main effect of: (i) treatment (ii) Numerical ability and (iii) Gender on students achievement in mathematics?

The result in table 1 revealed a significant outcome in respect of the main effect treatment on achievement in mathematics ($F_{1, 196}$) = 34.00; P < 0.05). This implies that there is a significant main effect of treatment on the students' achievement scores in mathematics.

In order to determine the magnitude of the mean achievement scores of students exposed to the treatment conditions, the results of the multiple classification analysis (MCA) presented in table 2 was used. The results revealed that with a grand mean of 16.198, in experimental 1 (PBIS) had highest adjusted mean score of 19.057 (16.198 + 2.859) while the control group (TGM) had lowest adjusted mean score of 13.977 (16.198 – 2.221). This shows tat the PBIS is significantly best than the other remaining three treatments used in this study with respect to students achievement in mathematics. The table also presents a value of Beta for the treatment as 0.217 which implies that the treatment as 0.217 which implies that the treatment accounts for 4.709 percent $(0.217)^2$ x 100% of the variation in the observed achievement in mathematics. This result is in agreement with the earlier findings of Iroegbu and Okpala (1998) show that a hands – on stratify that is learner centered (such as problem-based teaching instructional strategy) covered significantly improve physics achievement of secondary school students. This result is explicable considering that such as instructional strategy has potential for cultivating and growing a learner's level of cognitive development (West, 1992).

Concerning the main effects of Numerical ability on students achievement in mathematics, the result revealed that the outcome was significant ($F_{1, 196}$) = 23.322; P < 0.05).

In order to determine the magnitude of the mean achievement scores of students' numerical ability conditions, the result of the Multiple Classification Analysis (MCA) presented in table 2 was used. For the main effect of numerical ability, the high numerical ability had an adjusted mean score of 18.943 (16.198 + 2.745), while low numerical ability had an adjusted mean score of 10.641 (16.198 – 5.557). This shows that the students who also high numerical ability significantly performed better than the students with low numerical ability. The value of Beta for the Numerical ability as 0.417 which implies that numerical ability only accounts for 17.389 percent $(0.419)^2$ x 100% of the variation in the students achievement in mathematics. However, the significant effect of numerical ability on mathematics achievement underscores the need for mathematics students to pay serious attention to learning the subject like basic and further mathematics that can sharpen their numerical ability.

Perhaps, it could be suggested that school curriculum committee, practicing mathematics teacher showed co-operate to ensure that in the first three of secondary (Junior Secondary) students are exposed to relevant mathematics concepts / topics with a view to making item prepared for sciences in senior classes.

Concerning the main effects of Gender on students' achievement in mathematics, the result revealed that the outcome was significant ($F_{(1, 196)} = 0.5151; P < 0.05$).

In order to determine the magnificence of the mean achievement scores of Gender conditions, the results of the MCA presented in table 2 was used. For the main effect of gender, the Male group had an adjusted mean score of 13.372 (16.198 – 2.826) while the female group had an adjusted mean score of 19.743 (16.198 + 3.544). This clearly revealed that female students had better performance than the male students with respect to achievement in mathematics. The table 2 also indicates a Beta value of 0.338 for the Gender, which implies that the Gender above accounted for 11.42 percent of the variation in students' achievement in mathematics. This finding provides empirical support to earlier findings that established that the effect of the strategy on physics achievement in gender sensitive as revealed in the significant interaction (Iroegbu & Okpala, 1998). The finding that gender had significant effect on students' achievement in mathematics is explicable covering the views of Odogwu, (2002) that gender stereotyping is still very much in the Nigerian educated system. In addition, it could be hindering the education of girls in science, technology and mathematics courses, is actually in support of the view that as gender differences using observed in students achievement in secondary school mathematics are statistically significant.

Hence, the three variables when combined (treatment, numerical ability and gender) jointly accounted for 28.0% of the variation obtained in the students school in mathematics.

Research Question 2: Is there any significant interaction effect of

(i) treatment and numerical ability;
(ii) treatment and gender
(iii) Numerical ability and gender on students achievement in mathematics?.

The result in table 1 revealed a significant outcomes in respect of its interaction effect of treatment and numerical ability on students achievement in mathematics ($F_{(1,196)} = 1.588,\ P < 0.05$). This implies that this is significantly affected by the interaction effect of treatments (PBTS, PBIL, PBIM and TGM) and Numerical ability (Low and high abilities) on the students' achievement scores in mathematics. The findings agreed with Emeke & Adegoke (2001) and Adu (2002) that Numerical ability has influence on students' achievement. This claim is contrary to findings of Falaye (2006) and Opaleye (2008) that there is no interaction effect of the treatment and numerical ability level on students self perception.

Concerning the interaction effects of treatments and gender on the students' achievement in mathematics, the result in table 1 revealed significant outcome in respect of the interaction effects on the students achievement in mathematics ($F_{(1,196)} = 2.376,\ P < 0.05$). Therefore, this seems to be significant interaction effects of treatment and gender on the students' achievement in mathematics. This is in agreement with Onadeko, (2006) that the treatments had a positive effect on the cognitive achievement in physics of both gender and much better for males when numerical and graphing instructions are used concurrently in the teaching of physics lessons.

However, there is no significant interaction effect on the numerical ability and Gender on students' achievement in mathematics ($F_{(1,196)} = 0.242,\ P > 0.05$). This result contradicted the findings of Odogwu (2002), Onadeko (2006) that male students perform better than female students in cognitive achievement do, and they found that the boys show high expectations and better achievements than the girls do in all their experimental groups including the most girl friendly group.

Research Question 3: Is there any significant interaction effect of treatments, numerical ability and gender on students' achievement in mathematics?

The result in table 1 revealed no significant outcome in respect of the interaction effect of treatments, numerical ability and gender on students achievement in mathematics ($F_{1,169}) = 1.850$: $P > 0.05$). This implies that treatments (PBIS, PBIL, PBIM and TGM) have no significant influence on the students' achievement in mathematics.

Conclusion
The study results indicated that:
(i) Treatment and Numerical ability had main effect significant influence mathematics achievement of secondary school students but gender had no significant influence on MAT;
(ii) Numerical ability (high & low) did not interact with gender to influence MAT of the students and
(iii) The treatment did not interact with numerical ability and gender to influence MAT of the students.

It could thus be said that the PBIS instructional strategy is the most potent of the treatment conditions used in the present study. The assertion seems to be valid irrespective of the students' numerical ability and numerical ability – gender groupings.

In all, the independent variables (treatment and Numerical ability) and moderator variable (gender) when taken together could be used to explain 28.0% of the variation in MAT of the students – a level of explanation that is, considered significant ($P < 0.05$). The order of the contributions of the variables to this explanation is Numerical ability (17.39%) and followed by gender (11.42%) and the least in treatment (4.71%).

Recommendations and Implications
In the light of the entire results and associated discussion, the researcher shall recommend that:
1. Secondary school mathematics curriculum should be re organized to provide opportunities for students to choose the methods of carrying out experiments and projects in small groups (of 3 students) that would suit problem-based learning instructional strategy.
2. Practicing mathematics teachers should be encouraged to meet problem –based learning instructional strategy in small group (PBIS) irrespective of students' numerical ability, gender as well as gender – numerical ability groupings.
3. As the teachers implement this instructional strategy (PBIS), they should be less prescriptive and allow students to decade on how to carry out the mathematics activities themselves.

The implementation of these recommendations would lead to our ultimate goals of improving and potential of educating enhancing in mathematics at the senior secondary school level. Moreover, appropriate courses need be introduced into teacher education programme for the training teachers in these students of designing and developing useful learning packages for mathematics instructions.

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